Water-Supply and Irrigation Paper No. 187 Series M, General Hydrographic Investigations, 19

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

DETERMINATION OF STREAM FLOW DURING THE FROZEN SEASON

BY

H. K. BARROWS AND ROBERT E. HORTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
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DETERMINATION OF STREAM FLOW DURING THE FROZEN SEASON.

By H. K. Barrows and R. E. Horton.

IMPORTANCE OF WINTER RECORDS OF STREAM FLOW.

Estimates of the flow of rivers are now being made by the United States Geological Survey in all parts of the country. To a great extent these are based on daily gage readings and numerous current-meter measurements.

In the northern and central parts of the United States the streams may be closed by a more or less permanent ice cover for a considerable portion of the year. This period varies from nearly five months in the extreme north to a few weeks or less in the Central and Atlantic States.

The methods in use for estimating flow under open-channel conditions have become well defined, and the limits of accuracy are known to be reasonable. On the other hand, the laws governing the flow of rivers that are frozen over have been but little investigated, and methods for estimating the flow under such conditions have not been formulated. Moreover, in winter the measurement of precipitation is more difficult, and available data of this kind are much less accurate than in summer. Finally, there is not even an approximate relation between the snowfall and the stream flow, so that the failure to obtain winter records of flow at a gaging station means a considerable percentage of uncertainty as to the total run-off as well as to its distribution.

In the Northern States droughts are apt to occur in the late summer or fall and during the winter. At times this condition of drought may be nearly or quite continuous between these two periods, with its culmination in January or February. If there is no melting of snow during the winter, the inflow to streams that freeze is chiefly derived from springs, ground water, and lake storage, and in a long, cold winter, especially if it succeeds a period of low water, the minimum flow for the year may be reached and continue for some time. Estimates of flow, therefore, to be of conclusive value on streams utilized for water power, must embrace these winter periods of low water.

METHODS OF GAGING STREAMS DURING THE OPEN SEASON.

GENERAL STATEMENT.

The methods of stream gaging in common use by the United States Geological Survey contemplate especially the determination of discharge when streams are free from ice at or near the gaging stations. One object of the present paper is to determine what modifications of these methods are necessary to secure good results when the streams are ice covered. With this in view a brief description of open-water methods is given below.

In general a record of the fluctuations in stage is obtained by daily reading a gage or gages. Various methods are used to obtain a rating of the stream so that the discharge in second-feet can be determined from the gage readings. Three principal methods of rating are in use—(1) the weir method, in which a weir or dam is used and the flow is computed for a given gage height; (2) the velocity method, in which a series of current-meter or float gagings are made at a given cross section and a discharge rating curve is obtained for that cross section; (3) the slope method, in which observations are made of the mean cross section and surface slope in a stretch of the river, and the velocity is computed by the Chezy-Kutter formula, $V=C\sqrt{RS}$, a suitable value being assumed for the coefficient C.

WEIR METHOD.

Weirs of standard type with sharp crest can be used on small streams only, on account of the cost of installation and liability to injury. Where practicable, they offer the best facilities for determining the flow. The flow at dam stations is usually divided—part going over the dam, part through the wheels, and part through by-channels. A weir formula with modified coefficient is used to compute the flow over the dam. The wheels are used as meters, a record being kept of gate openings, head, etc. Flow through by-channels which at many dams occurs only at intervals, is computed by the use of weirs, orifices, etc. The sum of these components is the total discharge of the river at the section. The general methods used at stations of this character are fully described in Water-Supply Paper No. 150.

VELOCITY METHOD.

The determination of the rate of flow past a certain section of a stream at a given time is termed a "discharge measurement." This rate is the product of two factors—the mean velocity and the area of cross section. The mean velocity is a function of surface slope, wetted perimeter, roughness of bed, and the channel conditions at, above, and below the gage section. In this method it is assumed

that the stream bed is constant in form and position and that the mean velocity at any given stage will always be the same. Therefore a rating curve may be obtained by plotting the results of a sufficient number of discharge measurements at different stages. In making the measurements an arbitrary number of points, known as "measuring points," are laid off on a line perpendicular to the thread of the stream, and the velocity and depth are observed. These points are usually at regular intervals from 2 to 20 feet apart, depending on the size and condition of the stream. The current meter is commonly used for obtaining velocities, although in a few cases rod or tube floats are utilized for this purpose. The area is thus divided into small sections in which the velocity is observed and the discharge computed, and the sum of the values for these sections gives the total area and discharge. If a sufficient number of discharge measurements are made at different stages, a rating table can be constructed that will show the discharge at any stage of the stream. The methods used in selecting current-meter stations and in collecting data are fully described in Water-Supply Papers Nos. 94 and 95.

SLOPE METHOD.

The results obtained from the slope method are in general only roughly approximate, owing to the difficulty in obtaining accurate data and the uncertainty of the value to be used for *n* in Kutter's formula. The most common use of this method is in estimating flood discharge of streams when the only data available are the cross sections, the surface slope as shown by marks along the bank, and a knowledge of the general conditions.

Throughout this paper velocities are expressed in feet per second, gage heights in feet, and the volume of flow of streams in cubic feet per second, or second-feet.

CONDITIONS DURING THE WINTER SEASON.

FACTORS AFFECTING ICE FORMATION.

Rarely, if ever, in this country does a stream of any size freeze over throughout its whole length, there being usually short stretches that remain more or less open. Two important factors govern the formation of ice on streams—(1) the climatic or general temperature conditions; (2) the size and character of the stream and the conditions affecting its flow.

In California, Washington, and Oregon, and south of latitude 37°, with the exception of perhaps a portion of northern New Mexico and Arizona in the Rocky Mountain district, the rivers do not in general freeze over sufficiently to affect records of flow or to occasion any change in methods from those of the open season.

In the most general sense, the character of the bed and banks of a stream depends on its slope and the materials over which it flows. A stream will not freeze over unless the water has a temperature as low as 32° F. and is comparatively still. If the water is greatly agitated, needle ice will be formed instead of an ice cover. This tendency to form needle ice always exists at rapids, particularly if the stream bed is very rough. If the cold is extreme and long continued even such places may eventually become frozen—the freezing starting at the water's edge or around rocks and piers, where the velocity is lower, and extending toward the center of the stream. The result, however, is not in any case a smooth ice cover, but a piling up of very rough or "honeycombed" ice which may be partly supported by rocks.

Where dams have been constructed there is usually above the dam more or less pondage and a great diminution in velocity, so that such portions of a river freeze over very readily. Below the dam quick water is frequently left, and conditions may be the same as at rapids.

Any special conditions tending to raise the temperature of the water may have a marked effect on the time or manner of freezing over of a portion of a stream. Near the outlets of lakes or in streams fed by springs or ground water there may be a sufficient inflow of water having a temperature considerably above 32° F. to prevent wholly or at least for some time the formation of an ice cover. Such conditions are also potent in assisting the rapid wearing away of the under surface of the ice and, in general, they result in very unstable conditions as regards ice cover. The temperature of springs is ordinarily about equal to the average annual temperature of the locality, which is for the Northern States 40° to 50° F.

CLASSIFICATION OF WINTER CONDITIONS.

It is evident that streams of any considerable length can not be classified as a whole with regard to ice formation or winter conditions, for the reason that very diverse conditions may occur at different parts of the same stream. The conditions on short stretches of streams, and particularly on such stretches as need to be considered in selecting current-meter stations, may be classified as follows:

Classification of winter conditions at current-meter stations.

(1) Smooth, permanent ice cover.
(2) Tendency for anchor or needle ice to accumulate underneath ice cover.
(3) Unstable ice cover, due to—
   (*a*) Effect of warmer inflow from lakes or tributary streams.
   (*b*) Effect of inflow of ground water.
   (*c*) Effect of warm currents due to artificial causes, such as factory waste, etc.
   (*d*) Concentrated quick water and wearing away due to friction.
   (*e*) Considerable fluctuation in stage occasioned by winter freshets.
(4) Rough ice cover and piling up of ice due to quick water and rough bed.

(5) Tendency for ice jams to occur, with consequent backwater, etc.
(6) Streams that remain open altogether or freeze over thinly for short times, owing to—
  (a) Extremes of conditions as noted under (3).
  (b) High temperature, mainly in the southern portion of the area, subject to ice conditions in winter.

The above classification is intended for the ordinary winter. The winter of 1904–5 was much colder than the average, and many streams remained frozen over in places where ordinarily there would not be permanent ice. On the other hand, the winter of 1905–6 was remarkably mild, and ice was carried away by freshets at many points where this very rarely happens. A gaging station, then, can be only approximately fixed in any of the above classes.

The following tables summarize the winter conditions at 179 current-meter stations and 25 dam stations:

Summary of winter conditions at current meter stations.

Class.	New England.	New York and lower Michigan.	Atlantic States.	Central States.
(1) Smooth, permanent ice cover	11	11	13	35
(2) Tendency for anchor and needle ice to accumulate	4	5	2	(a)
(3) Unstable ice cover	10	3	21	9
(4) Rough ice cover and piling up	7	3	6	(a)
(5) Tendency for ice jams	1	1	8	(a)
(6) Remain open	5	10	7	7
	38	33	57	51

a Not reported in detail.

Of the 179 stations considered 29 remain unfrozen thruout the winter, and at these stream flow can be estimated in the same manner as during the open season. Smooth, permanent ice cover is found at 70 stations. The remaining 80 stations have miscellaneous conditions, all of which are probably unfavorable for estimating winter flow.

Summary of winter conditions at stations at dams.

Good conditions for estimates, crest unobstructed, ice cut away, or water mostly used by wheels	13
Poor conditions for estimates, crest seriously obstructed	12
	25

DURATION OF ICE SEASON.

The following table gives the usual duration of ice cover in different areas where the streams freeze during the winter.

Duration of ice cover, by areas.

Locality.	Date of closing in.	Date of breaking up.	Time frozen.
			Months.
Northern Maine	November 15–30	March 15–April 15	$3\frac{1}{2}$–5
Northern Michigan	December 1–30	March 1–15	2 –$3\frac{1}{2}$
Lower New England	December 15–January 1	February 15–March 15	$1\frac{1}{2}$–3
New York	December 1–15	March 15–31	3 –4
Pennsylvania	January 1–15	March 1–15	$1\frac{1}{2}$–$2\frac{1}{2}$
Illinois	December 15–January 15	February 15–March 1	1 –$2\frac{1}{2}$
North Dakota	November 15–30	March 15–31	$3\frac{1}{2}$–$4\frac{1}{2}$

A large amount of information relating to the duration of the ice season, especially with regard to lakes and navigable streams, was published in the report of the United States Deep Waterways Commission.[a] A few of the results for rivers there given are compiled in the following table:

Duration of ice cover on northern streams.

River.	Locality.	Length of record.	Average date of— Closing.	Average date of— Opening.	Time closed.
		Years.			*Days.*
Connecticut	Hartford, Conn	42	Dec. 12	Mar. 12	90
Do	Turners Falls, Mass	12	Dec. 9	Mar. 16	97
Hudson	Albany, N. Y	87	Dec. 15	Mar. 20	95
Illinois	Peoria, Ill	53	Dec. 17	Feb. 21	66
Merrimac	Amoskeag, N. H	18	Nov. 28	Mar. 19	111
Mississippi	Davenport, Iowa	25	Dec. 12	Mar. 19	97
Do	St. Louis, Mo	31	Dec. 19	Jan. 20	32
Missouri	Bismarck, N. Dak	24	Nov. 25	Mar. 31	126
Do	Fort Buford, N. Dak	15	Nov. 15	Apr. 13	151
Ohio	Cincinnati, Ohio	39	Jan. 15	Jan. 25	10

CHANGE IN THICKNESS OF ICE.

After a stream becomes frozen over, the thickness of the ice usually increases rapidly, reaching a maximum generally by midwinter and then remaining nearly constant until shortly before the open-water season begins. As a rule there is some melting and thinning of the ice before it goes out, but a heavy early spring freshet may carry out ice at its maximum thickness.

The following table shows the ice thickness at intervals through the winter at two fairly typical gaging stations.

Thickness of ice on Connecticut River at Orford, N. H., and Esopus Creek at Kingston, N. Y.

Date.	Connecticut River at Orford, N. H.			Esopus Creek at Kingston, N. Y.		
	1903–4.	1904–5.	1905–6.	1903–4.	1904–5.	1905–6.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
November 15	....	0	0	....	....	....
December 1	....	.3	.1	0	0	0
December 15	0	.7	0	0	.4	.1
January 1	....	1.3	0	.5	.65	.4
January 15	1.7	1.5	.7	.95	.6	.5
February 1	1.85	1.7	0	1.1	1.25	.75
February 15	1.9	2.1	1.05	1.25	1.5	.9
March 1	2.1	2.2	1.15	1.25	1.6	.4
March 15	±2.	2.1	1.1	.6	.7	.25
March 30	0	0	0	[a] 0	[a] 0	[a] 0

[a] March 31.

SURFACE, ANCHOR, AND NEEDLE ICE.

The three following forms of ice occur in streams and each of them affects the flow in a different way: (1) Cake, border, or surface ice; (2) needle ice, or "frazil," so called from the French word signifying

[a] House Doc. 192, 54th Cong., 2d sess.

"forge cinders," which are suggested by its dull, slushy appearance; (3) anchor ice, which closely resembles needle ice, but which is formed in a different manner.

Surface ice is formed when the temperature of a quiet body of water becomes 32° F. As the maximum density of water occurs at 39.1°, the temperature of a quiet body of water that is cooled from the surface will gradually increase from the surface downward after a general water temperature of 39.1° has been reached. Surface ice probably always begins to form at the shore or at the borders of solid objects and is extended by spicules shooting out and forming a network, the process being analogous to the growth of crystals in a saturated solution except that ice is formed at the surface only. The surface layer of ice gradually increases in thickness and continues to grow as long as the air temperature is below 32° F. The rate of such increase varies with the temperature and other atmospheric conditions affecting heat radiation. The thickness of the ice layer increases in nearly direct proportion to the square root of the time. Surface ice also forms over smooth-flowing water, but as the velocity and roughness of the current are increased a condition is soon reached where the projecting ice needles are broken off as fast as they are foremd.

It is obvious that the surface temperature of a stream passing over rapids where surface ice can not form would often fall below 32° F. if a portion of the water were not converted into ice in some manner and enough latent heat released to maintain the temperature constantly at 32°. It is well known that perfectly quiet water can be cooled below 32° F. without the formation of ice, apparently because the necessary nuclei and other conditions to start ice formation are not present. If, however, the slightest motion occurs, the water molecules are enabled to assume the arrangement necessary to crystallization and the water becomes filled with ice spicules.

Elaborate experiments by Prof. Howard T. Barnes by means of an electrical-resistance thermometer indicate that flowing water in a stream can not be cooled more than one one-hundredth of a degree below the freezing temperature without the formation of ice. The ice spicules that form in agitated water vary in character with the variations in the rate of their formation. Elongated needles, cubical crystals, and broad, thin plates have been observed under different conditions. Apparently the stream may be filled with needle ice formed in the manner described without the flow being affected in any considerable degree. If, however, the needle ice is carried underneath the layer of surface ice, it forms an effective obstruction.

Observations in St. Lawrence River indicate that masses of needle ice may travel under the surface ice for several miles. There is undoubtedly some flow through these masses, but the velocity is very

slight. It has not been found possible to measure the flow through such ice with the current meter. The existence of flow is, however, indicated by the presence of impurities in the ice. A striking illustration of this flow is also given in fig. 1, which shows two cross sections of Chemung River. At the upper section the channel underneath the surface ice was almost completely blocked by needle ice, while at the lower section, 200 feet downstream, there was but little needle ice;

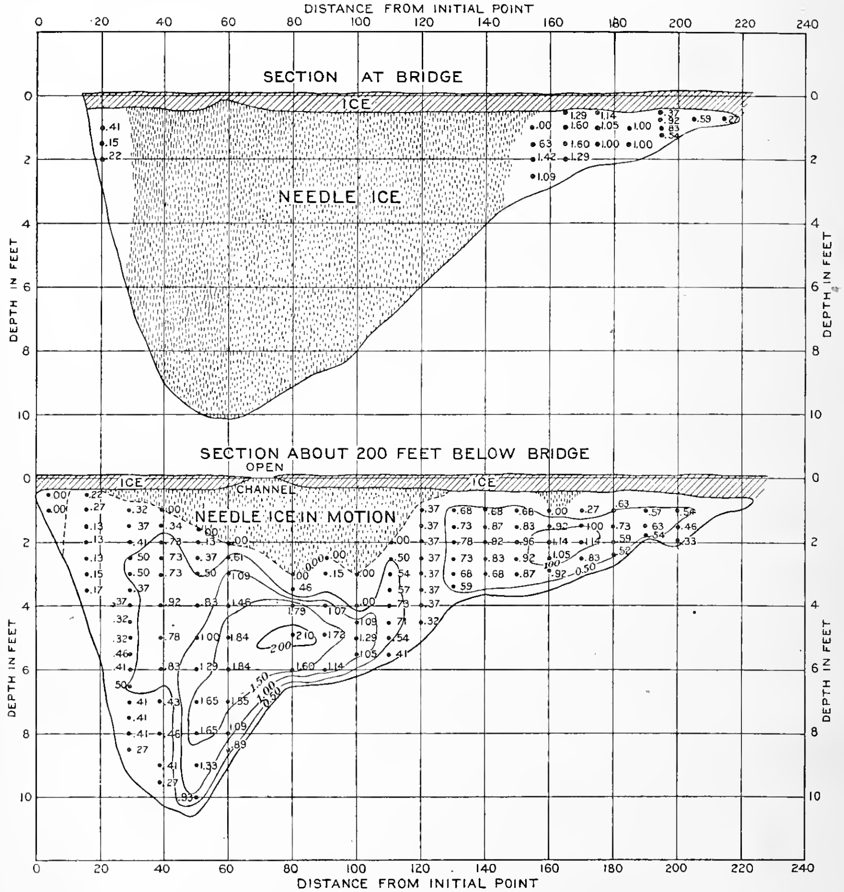


FIG. 1.—Cross sections of Chemung River at Chemung, N. Y., showing effect of needle ice.

yet the observed velocities at the lower section were so great as to indicate that considerable flow through the masses of needle ice must have taken place.

Gage readings or attempts to estimate the winter flow of streams at cross sections affected by needle ice are apparently worthless. Although the general features of ice formation in a given locality will be the same from year to year, a consideration of the conditions of needle-

ice formation shows that the differences will be sufficient to produce in effect a constantly changing regimen. The formation of needle ice, like that of surface or anchor ice, is due chiefly to radiation of heat from the water mass. Needle ice never forms underneath surface ice and is most frequently formed on cold, clear nights, when the heat lost by radiation is most greatly in excess of that received at the earth's surface. Professor Barnes states that the margin between the disintegration and the formation of the ice is exceedingly narrow, amounting to only a few thousandths of a degree change of temperature, the radiation and the absorption of the sun's rays by water being controlling factors.

Snow falling on the surface of a stream becomes water-logged and forms a slush resembling floating needle ice. Snow crystals probably often form the nucleus of masses of needle ice, but the presence of snow is not an essential or important condition for the occurrence of such ice, as is sometimes supposed.

Anchor ice is sometimes formed when stones or other objects in a stream are cooled by radiation to 32° F. It is a crystalline growth similar to needle ice and having the same density. It remains attached to the objects upon which it is formed as long as their surface temperature is below 32°. Like needle ice, it forms most readily when the difference between radiation and absorption is a maximum. Apparently it never forms underneath surface ice; but whenever the relative loss by radiation is decreased, as, for instance, on a cloudy day, it may become detached and rise to the surface, carrying with it stones or other objects. It affects the regimen of streams chiefly by forming obstructions in portions of the channels that do not freeze over, thereby causing back water, or by rising and floating underneath the surface ice, as needle ice often does. Anchor ice does not ordinarily form in streams with earth beds and apparently forms more extensively on dark-colored rocks, radiation from dark objects being greater than from light ones.[a]

RANGE OF WINTER GAGE HEIGHTS.

Data regarding extremes of winter gage heights are given in connection with station descriptions (pp. 26–38). In general, winter freshets are uncommon in the northern portion of the area, in which the streams freeze and the range in stage is small, but the liability of their occurrence increases rapidly to the south. They are, however, usually not of long duration, and are not serious factors in winter

[a] Rept. Commission of Engineers on Floods, Montreal, 1890. Henshaw, Geo. H. Frazil ice: Trans. Canadian Soc. Civil Eng. vol. 1, pp. 1–23. Barnes, Howard T., Formation and agglomeration of frazil and anchor ice: Canadian Engineer, May, 1897, pp. 6–10; Formation of anchor ice and precise temperature measurements: Trans. Am. Soc. Mech. Eng., 1905. Horton, R. E., Anchor ice and frazil: Paper Trade Journal, December 24, 1903.

estimates unless they are of sufficient size to cause the ice to break up and go out more or less completely, when the conditions of flow may become entirely changed. As a rule the regimen of flow changes less in winter than during the open season.

FLOW OF STREAMS UNDER ICE COVER.

GENERAL CONSIDERATIONS.

In the Chezy formulas

$$Q = A\,V$$
$$V = C\sqrt{R\,S}$$

C is the coefficient dependent on the physical character of the stream bed and the hydraulic radius. The physical character enters into the determination of C in the form of a coefficient of roughness, n. The relation of n, R, and C, as deduced by Kutter, is as follows (for English units):

$$C = \frac{41.66 + \frac{1.811}{n} + \frac{0.00281}{S}}{1 + \left(41.66 + \frac{0.00281}{S}\right)\frac{n}{\sqrt{R}}}$$

It will be seen that for a given slope and hydraulic radius the mean velocity of a stream is nearly proportional to $1 \div n$; that is, the velocity is inversely proportional to the roughness of the stream bed. The Chezy and Kutter formulas are empirical and in their application values of n determined from previous experiments are selected by judgment.

FRICTION DUE TO AIR AND ICE.

If V, R, and S are given, the value of n may be calculated from the Kutter formula. In such calculations for open-channel conditions the hydraulic radius is taken as the ratio of area of cross section to the wetted perimeter, not including the surface in contact with the air. It is probably true, however, that the mean velocity of a stream is usually less than it would be if there was no friction between water and air.

If the air-contact surface is replaced by a film of ice, then, in making a calculation of C or of the velocity, the entire wetted perimeter, including that portion of the boundary of the stream section in contact with ice, would naturally be included in calculating the hydraulic radius.

If the value of n is derived by considering the wetted perimeter as including the air and ice contacts as well as those of bed and banks, and if the frictional resistance of the water-ice contact is greater than

the frictional resistance of the water-air contact, then n will have a correspondingly greater value for conditions of ice cover than for those of open channel. In other words, the ice cover increases total friction by an amount representing the difference between air and ice resistance and not by an amount representing the total ice friction.

The ordinary friction of a stream bed may be considered as made up of two parts—(1) skin friction and (2) internal motion.

In most instances a film of water adheres to the surface of solid objects over which the water flows, and the skin friction between the water and these objects is essentially the same as that between two fluid surfaces. It is measured by the viscosity of the liquid, the energy absorbed probably being for the most part converted into heat.

If the stream bed is rough, the impact of the water creates swirls or eddies, in which a portion of the energy is converted into internal or vortex motion not useful in causing forward motion.

So far as known, no experiments have been made relative to the skin friction of a smooth ice surface. It may be assumed, however, to be about the same as for a smooth glass or planed-wood surface, especially the latter. A layer of water adheres to such a surface or is entrapped by the capillaries, so that the friction surface is essentially a layer of liquid particles, the conditions thus closely resembling those where water at 32° F. is in contact with ice.

The value for glass or planed-wood surfaces of n in Kutter's formula is given by various authorities as about 0.009, or from one-fourth to one-third the resistance due to an ordinary stream bed. When the under ice surface is rough, broken, tilted, or honeycombed, its impact resistance may become of the same or even greater relative importance than that of an earth or rock surface. It is presumable that cases are rare where the under surface of the ice cover is so free from irregularities as to give a value of n as low as those applying to glass or planed wood.

Occasionally a layer of needle ice of varying thickness floats under or accumulates on the lower surface of the ice cover. Such ice not only obstructs the flow through the portion of the cross section occupied, but also greatly increases the friction as compared with that of a smooth ice surface.

RELATIVE IMPORTANCE OF AIR AND ICE FRICTION.

As already pointed out, the actual increase in friction due to an ice cover is the difference between the ice friction and the air friction previous to the formation of the ice cover. Owing to the divergent opinions entertained as to the magnitude of air friction, it has been thought well to discuss the matter somewhat at length.

In the Chezy formula and in most other similar slope formulas it is assumed that all the resistance to the motion of the water proceeds from the stream bed. Humphreys and Abbot[a] found, however, that the position of the point of maximum velocity in vertical velocity curves on Mississippi River was controlled by the direction and velocity of the wind. They give the following expression:

$$d=(0.317+0.06f)\ D$$

In this formula D=depth in feet; d=depth of point of maximum velocity; f=relative wind velocity on a scale such that a calm=0 and a hurricane=10.

In deriving a formula for the mean velocity of streams in terms of the slope and hydraulic radius, Humphreys and Abbot assumed that the frictional resistance between the water and air contact surfaces was similar in nature and magnitude to the bed resistance. In their formula, accordingly, the hydraulic radius is expressed as follows:

$$R=\frac{A}{P+W}$$

In this formula A = area of cross section, P = wetted perimeter in earth, W = width of surface.

In discussing the results of Humphreys and Abbot's investigations, the late James B. Francis made the following clear statement as to the effect of air friction:[b]

> When the air in contact with the surface of the water flowing in an open channel is moving in the same direction and with the same velocity as the surface of the water, it is clear that it can have no effect on the motion of the water; but such exact conformity in the motion of the air and water is uncommon; ordinarily the air has some motion relatively to that of the water and either retards or accelerates the velocity of the surface. That the air may produce a material effect on the scale of velocities is apparent from the following considerations.
>
> Let us suppose the surface of the water to move, relatively to the air, with the same velocity that the water at the bottom moves relatively to the bed; also that the inequalities of the surface of the water caused by the action of the air and those in the bed of the stream are alike; and suppose, also, that a sheet of water of uniform thickness, in contact with the bed, is at rest; we shall then have the water near the bottom moving over a bed of water and the water at the surface moving under a bed of air, and as both beds have the same inequalities, they will cause the same retardation in the velocity of the water, except as these beds, from the nature of the substances of which they are composed, offer more or less resistance. These resistances will be of the same nature as is experienced by a body moving in a resisting medium. According to well-known principles, the retardation in this case is as the square of the velocity of the moving body relatively to that of the medium and as the density of the medium. The density of the air is about $\frac{1}{810}$ of that of water; a body moving through the air with the same velocity will therefore be retarded $\frac{1}{810}$ as much as if it moved through water.

The above conclusions are confirmed by a comparison of the coefficients that have been determined experimentally for use in comput-

[a] Physics and Hydraulics of Mississippi River, p. 305.
[b] Lowell Hydraulic Experiments, pp. 158-159.

ing loss of pressure occasioned by the flowing of air and water through pipes, the form of expression adopted by Weisbach being used:

$$p=f\frac{l}{d}\frac{v^2}{2g}$$

In this formula p=loss of pressure in pounds per square inch; l=length of pipe in feet; d=diameter of pipe in inches; v=mean velocity in feet per second; f=coefficient of resistance to flow.

Rough average values of the coefficient f, according to Weisbach's experiments, may be taken as follows: For air, f=0.000160; for water, f=0.104, the relative friction loss for water being 650 times that for air.

It seems probable, then, that with still air the frictional effect of air on water surface is but a small percentage of that due to stream bed, although with a strong wind upstream the retardation of the filaments of water near the surface may be considerable.

VARIATION IN SLOPE DUE TO FREEZING.

As an ordinary stream is made up of smooth-water reaches separated by more or less pronounced rapids, and as the swiftest portions of a stream freeze least readily, the freezing of a stream will

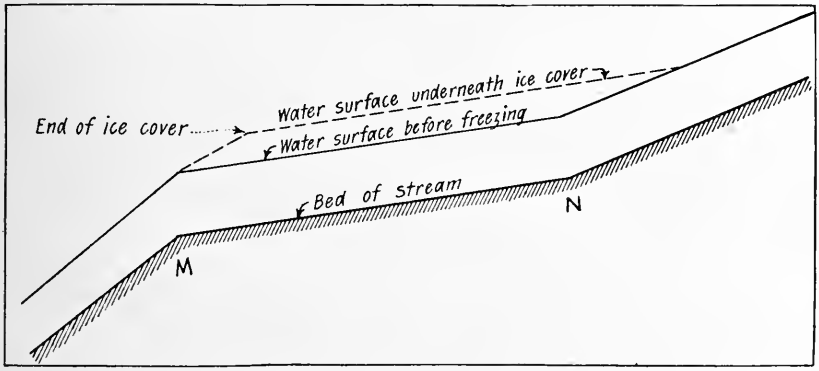


FIG. 2.—Effect of freezing on a smooth section of a river terminated by rapids.

lead to the following conditions: (1) There will be an increase in the total friction due to replacing the water-air contact surface by water-ice contact surface; (2) if the discharge remains the same, it follows that with increased friction either the slope or the cross-sectional area must increase.

In a long, uniform channel, frozen throughout, there can be but little or no increase in slope; but in short reaches separated by open water, such as those where gaging stations are commonly located, an appreciable local increase in slope due to freezing may easily occur, as shown in fig. 2. As a result of freezing of the smooth-water reach

M N there is a tendency for the stage to be raised, as shown by the dotted line, and the upper stretch of quick water above N may be partly submerged by backwater. If the discharge remains the same the depth of open water at M will not be increased unless there is backwater here due to ice cover below this point. If the depth at M is not increased, the fall of the water surface between N and M will have been increased. There is no actual increase in slope, except in the vicinity of M, and the ice surface adjusts itself parallel to the channel bed, as in the case of flow in an open channel, but the effective fall from N to M is of course increased.

CHANGE IN AREA OF WATERWAY REQUIRED BY FREEZING.

The conditions that occur when a broad river becomes covered with a uniform ice surface are illustrated by the following example: Consider a rectangular channel in which the width B D is many times the depth, so that the wetted perimeter may be taken as approximately equal to the width. Neglecting the air friction, call the coefficient of roughness applying to the channel n_1. Consider also that the cover E F may be brought just in contact with the stream surface, the coefficient of roughness for this ice cover being n_2. The slope and discharge being assumed to remain constant, the effect of cover of varying roughness may be illustrated as follows:

Let width B D = 500 feet,
slope S = 0.0005,
depth D = 5 feet,
area of section = 2,500 square feet,
wetted perimeter = 500 feet approximately,
hydraulic radius = 5 feet approximately.

Then for $n = 0.030$, as in an ordinary river, the mean velocity would be 3.29 feet per second, and the discharge would be 8,225 second-feet.

If, now, the stream is covered over, if n_1 and n_2 equal 0.030 each, and if the discharge is the same as before, then the stream stage must evidently rise in such manner that the increase in C, resulting from increased hydraulic radius, together with the increase in R and A, will counterbalance the increased friction. Owing to the complexity of the Kutter formula, the result can best be determined by successive approximations rather than by analysis.

We will have, if D remains as before,

$R = 2.5$ $V = 2.01$ $Q = 5{,}025$

If D is increased 1 foot,

$R = 3.0$ $V = 2.29$ $A = 3{,}000$ $Q = 6{,}870$

If D is increased 2 feet,

$R = 3.5$ $V = 2.56$ $A = 3{,}500$ $Q = 8{,}960$

By interpolation between the last two values it appears that the

stage must increase about 1.65 feet in order that the discharge shall be the same as for open channel. If, on the other hand, the value of n_2 for the covered surface was 0.010, then since the wetted perimeter for the bed and for the covered surface are approximately the same, the average coefficient of roughness for the entire stream section would be

$$\frac{0.010+0.030}{2}=0.02$$

With this value of n, in order to give the original discharge of 8,225, the stage would need to be raised about 0.2 foot.

In actual streams the wetted perimeter of the stream bed will usually be somewhat more than half of the total cross-sectional boundary; furthermore, as shown elsewhere (pp. 14–15), when the stream is covered, the effect is to replace air-surface friction by ice-surface friction; so that, all things considered, the presence of a thin, smooth ice cover will probably not necessitate any very great increase in stage in order to maintain the discharge undiminished.

As a river becomes nearly or quite frozen over and the thickness of ice increases, the diminution of area of water may be considerable. In the example previously quoted, for the given stage the area of waterway would be reduced as follows (if the ice is floating):

Effect of thickness of ice on area of waterway.

Thickness of ice.	Reduction in area of waterway.	
Feet.	*Sq. ft.*	*Per cent.*
0.5	230	9.2
1	460	18.4
1.5	690	27.6
2	920	36.8

With ice 2 feet thick, then—which is not uncommon—there would be a reduction in area of about 37 per cent. In the example, above, a rise of stage of 0.2 foot was occasioned by thin ice cover. With 2 feet thickness of ice a further rise of about 1.84 feet, with no snow load upon the ice, would be required to insure the same discharge. The total necessary rise of stage would then be 2.04 feet.

EFFECT OF THICKNESS OF ICE ON FLOW.

It is evident that the discharge for a given gage height, taken to the water surface where there is a thick ice cover, may be diminished very materially as compared with that for open-water conditions.

By further considering the data on page 18, and also assuming a change in depth (or gage height) from 5 to 8 feet, we obtain the following:

Relation of gage height to discharge.

[S = 0.0005; n = 0.030 for open water; n = 0.020 for thin ice cover.]

Depth (or gage height).	Discharge (open section).	Ratio Discharge under ice cover. / Discharge for open section. Thin ice.	Ice 1 foot thick.	Ice 2 feet thick.
Feet.	*Second-feet.*			
5.0	8,225	0.91	0.65	0.42
6.0	11,200	.91	.70	.49
7.0	14,500	.92	.73	.55
8.0	18,200	.92	.74	.59

For the rectangular section as chosen this indicates that for a given stage the ratio of discharge under ice cover to that for open section diminishes as the ice thickness increases; for thin ice cover it is

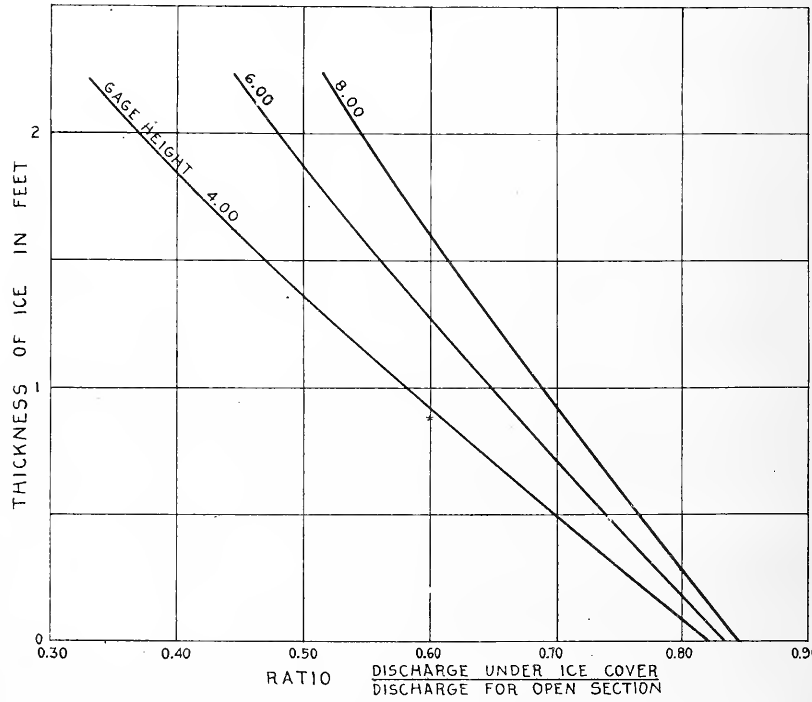


FIG. 3.—Effect of change in stage on discharge under ice cover, with varying thickness of ice.

approximately constant for ordinary stages, but as the ice thickens, the effect on the ratio is much greater at the lower gage heights. To further illustrate this tendency, fig. 3 has been prepared. The properties of the gaging cross section of the Connecticut River at Orford, N. H., are here used (at gage height 4.0; area = 1,280; width = 267; hydraulic radius = 4.76; slope assumed as 0.00012; n = 0.035 for open-water conditions; and n = 0.025 for channel frozen). Under these assumptions with thin ice, the relation between discharge under ice

cover and that for open water is nearly constant for ordinary stages; for thick ice this relation may vary 25 or 30 per cent in this range of gage heights (which is about the usual winter range at this station), the tendency being for this ratio to increase as gage heights increase.

The effect of a thickening ice cover for given conditions of slope and roughness and for a given gage height is as follows: (1) To diminish the cross-sectional area; (2) to slightly diminish the wetted perimeter, by lessening the width; (3) to decrease the hydraulic radius as a result of the loss of area while the wetted perimeter changes only slightly.

Changes of area and hydraulic radius both tend to diminish flow. It is evident that the relative effect of this diminution will become less and less as stage increases, for both area and hydraulic radius increase directly as the gage height, while the loss of area and hydraulic radius for a given thickness of ice is approximately the same at any ordinary stage.

METHODS OF OBTAINING WINTER RECORDS.

CURRENT-METER STATIONS.

GAGE HEIGHTS.

Previous to the winter of 1903–4 records of gage heights for the frozen season were not in general obtained, the exception being in the case of a few gaging stations on Catskill Mountain streams in the vicinity of New York City, where the attempt was made to procure continuous records from the time of their establishment in 1901. Since 1903 gage heights have been procured during the winter at a considerable number of stations in the Eastern and Central States. An effort has been made to obtain data bearing on both the stage of the river and ice conditions.

The observer is not expected to read the gage and obtain the attendant ice data oftener than once or twice a week unless unusual conditions prevail (such as high water, due to rains or melting snow), as the change in stage under ice cover is usually a slow and even one. The essentials in these observations are as follows: (1) A hole is cut in the ice at (or underneath) the gage, the gage is read to the water surface and to the top of the ice, and the thickness of the ice is measured; (2) any special conditions are noted, either in remarks or by sketch, such as areas of open water, backwater effect due to ice jams, etc. Observers are instructed to measure the thickness of ice occasionally at other places in the cross section at the gage and at points up and down stream. For these winter duties observers are furnished with an ice chisel and an ice-measurement stick, so arranged with an L end that the bottom of the ice can be definitely located and the thickness noted.

The transition periods from open channel to frozen conditions in the fall and the reverse in the spring are important. During the fall-transition period, while the river is freezing, two methods have been

used for gage readings, as follows: (1) Daily gage readings to the top of the ice are made continuously, until the ice is strong enough to walk on, the date of first freezing having been noted. After the ice cover forms the usual winter observations begin, as previously described. (2) The ice is broken daily under the gage, a good-sized hole being made with a weight and rope provided for the purpose, and gage heights are read to the water surface, until the ice is strong enough to walk on, when the thickness can be noted and the usual method followed.

In spring when the ice goes out daily gage readings begin with any considerable increase in stage and conditions as to ice—time of ice going out and of river being clear from ice, etc.—are noted. If at any time during the winter high water occurs or the ice goes out, daily gage readings are resumed until steady conditions once more prevail.

CURRENT-METER DISCHARGE MEASUREMENTS.

Holes are cut in the ice at points in the cross section where it is desired to obtain velocity determinations. These holes can be cut usually to best advantage with an ice chisel and are made only large enough to allow the ready lowering of the current meter through them. A rectangular hole 12 by 24 inches, with its length in the direction of the cross section and with vertical sides, has been found convenient for thick ice; lesser dimensions may be used where the ice is thin. In a few cases it has been necessary to cut a continuous channel between two or more adjacent holes, especially where the holes are close together, to prevent rapid vertical pulsations of water in the holes. Where a large number of holes are to be cut, a special auger cutting out a cylindrical core of ice has been used to advantage by United States Army engineers. The auger is driven by hand, by means of a suitable framework and gearing, similar to a carpenter's frame boring machine.

The cross section at which open-water discharge measurements are made is always used, when possible, as more direct comparisons can thus be made of the various features of flow under ice cover, with similar data for open channel. If, as sometimes happens, it is desirable that the measurements of flow under ice cover be made at a different or auxiliary section in order to obtain more favorable conditions, it is necessary to install an auxiliary gage or reference point, or, by sufficient soundings at the section used to keep control of the area, positions of ice surfaces, etc.

Soundings are always referred to the surface of the water in the holes, and, in addition, the distance from the water surface to the top and the bottom of the ice is noted. The depth of snow covering the ice, if any, is also noted and if possible a determination made of its

water equivalent. The character of the ice and of its under surface is noted, especially with regard to smoothness.

Gage heights are taken to the water surface and the top of the ice in the same way as by the observer, but, in addition, especially if an auxiliary section is being used for the current meter, holes are cut in the gage cross section and a little distance up and down stream in sufficient number to get a good average determination of the thickness of the ice and its position relative to the water surface.

Velocity observations have been most generally made by the vertical velocity-curve method, or at least a sufficient number of curves have been obtained to give good control of any single or double point method. Vertical velocity curves have also been very frequently taken for the reason that data were thus obtained for study and for the devising of shorter methods of observation.

A double-point method giving good results was developed from data obtained in 1904 and was used in measurements for the next two seasons. This consists in making observations at 0.2 and 0.8 of the total depth (below the bottom of the ice), the mean of these two velocities being very nearly the mean velocity of the vertical.

Single-point methods, in which the velocity is determined at 0.4, 0.6, or mid depth, are sometimes used, it being necessary to have vertical velocity curves at the same points and taken under similar conditions in order to deduce the mean velocity from the observed velocity.

Vertical integration has been used to a limited extent, but it has not been found as convenient as the methods previously described and it gives no data for the study of the vertical velocity curve. It is also objectionable owing to the difficulty of properly handling the current-meter cable, which becomes wet and covered with ice.

The horizontal distance between velocity observations should probably be about the same as for open water for the best results, but frequently it is advisable to extend it somewhat beyond that limit, in order to reduce the labor required for cutting holes in the ice.

The current meter is used either suspended by a cable in the ordinary manner or fastened to a wooden or metal rod. If a cable is used, it is marked at intervals of 0.5 or 1 foot by small lengths of cord wound and tied about it for use in sounding and placing the meter. It is most convenient to refer these to the center of the meter and add to soundings the distance from the center of the meter to the bottom of the weight. If a rod is used (this is of course limited to comparatively small depths and low velocities), it may be graduated from the center of the meter in a similar way. The rating of the small Price meter when it is fastened to a rod, but free to tip on its horizontal axis, is almost identical with that when the meter is suspended by a cable in the usual way.

The meter must be kept in the water continuously, or nearly so, if the temperature of the air is much below freezing, as ice will form very quickly on exposure and perhaps cause the meter wheel to stick. If the temperature is very low, trouble is also experienced from ice gathering on the cable or rod supporting the meter.

Measurements during inclement weather can often be most conveniently made under a shelter consisting of a framework of light boards or poles covered with canvas. A cross plank at a height of about 3 feet serves as a convenient support for instruments and stop watches, as well as a datum for lowering the meter in making vertical velocity curves.

In moving from station to station the meter is drawn up until it clears the ice and left suspended from the cross plank while the entire shelter is carried forward to the next point of measurement. By this method the necessity of handling the wet cable, often troublesome, even when rubber mittens are used, is generally avoided.

The additional cost of measurements on frozen streams over that for the open season is occasioned by the following conditions: (1) General difficulty of field work during cold weather, and consequently longer time required; (2) labor required to cut holes in ice and perhaps clear off snow; (3) longer methods required in gaging. The following table gives data regarding the cost of gaging under ice cover at certain stations during 1904–1906 as compared with the cost of gagings made under open-water conditions.

Cost of current-measurements under ice cover.

Locality.	Number of stations.	Year.	Number of gagings.	Average cost per gaging, exclusive of travel to and from station.	Average total cost per gaging.	Usual total cost per gaging, river open.
New England	1	1904	4	$30.52	$34.64	$10.00
Do	3	1905	7	16.67	18.82	8.57
Do	4	1906	19	14.18	15.65	10.42
New York	9	1906	15	18.24	22.13	10.32

The "usual total cost per gaging, river open," is based on a record of actual costs during 1904 and 1905 for New England and from July, 1904, to July, 1905, for New York stations. During the greater part of the 1906 winter gagings in New England only one hydrographer was in the field, laborers being employed for the work of cutting holes in the ice and assisting in gaging. Previous to that time there were usually two hydrographers. All New York gagings have been made by two hydrographers.

The average cost per gaging for ice cover, exclusive of travel, is from one and one-half to three times that for open-water conditions.

A. GAGING STATION ON SANDY RIVER AT MADISON, ME., AT DAM OF MADISON ELECTRIC COMPANY

B. GAGING STATION ON WINOOSKI RIVER AT RICHMOND, VT.

STATIONS AT DAMS.

A considerable number of the gaging stations of the Survey are at water-power plants, and records are obtained by observing the flow over the dam, the wheel-gate openings, etc., and the amount of water used by wheels.

During cold weather ice may form in large quantities on the crest of a dam and vitiate the computations made from gage heights of flow over the dam. Pl. I, *A*, gives an excellent illustration of the manner in which ice may form upon a dam. This plate shows one of the regular stations of the Survey at Madison, Me. In some cases this difficulty can be obviated by keeping the ice cut away from the crest, as is frequently done at an electric-light and power plant; or where that is impracticable, a record of ice conditions, with proper corrections, may serve to make approximate estimates.

The flow through turbines is as easily determined in winter as in summer. Frequently the greater part of the flow is taken through the wheels. Gaging stations at dams and mills usually afford better opportunities for securing winter records than exist at many current-meter stations.

ESTIMATES FROM PRECIPITATION.

Methods of estimating stream flow from precipitation are so generally known as to require no detailed explanation. In most such estimates the run-off in any month is determined from the contemporaneous precipitation by the use of a ratio or reduction factor. In crude estimates it is assumed that a constant percentage of the precipitation will appear as run-off regardless of the amount of precipitation. In more exact work a sliding scale of coefficients is used, the values depending on the amount of precipitation and the month or season.

For precipitous and impervious basins the run-off will be nearly coincident with the precipitation. If, however, there are lakes, forests, extensive ground-water storage, or accumulated snow within the basin, the precipitation in one month may not appear as run-off for a considerable interval of time, and any attempt to estimate the run-off for any month from the contemporaneous precipitation will be valueless. This is especially true in basins where much of the winter precipitation is in the form of snow, which accumulates on the ground, especially in ravines and forests, so that water representing several inches depth on the drainage basin may be carried forward from month to month, or from one calendar year to another, without entering the stream.

A heavy precipitation in the form of snow may occur without any appreciable effect on the stream flow. On the other hand, whenever the temperature rises above 32° F., run-off from melting snow occurs,

and often the entire winter's snow storage enters the stream in the course of a few days. During from one to three months of the spring freshet season northern streams generally show a run-off considerably in excess of the contemporaneous precipitation.

Data regarding the evaporation loss from snow-covered surfaces are very meager. If records of the snowfall, snow accumulation, and temperature are at hand it may be possible to form estimates of the total run-off of a stream for the winter season. It is obviously impossible at present to form reliable estimates of winter flow for shorter periods from precipitation data alone in any manner similar to that commonly used in estimating the flow from the rainfall during the summer months.

The minimum flow of a stream, either in summer or winter, ordinarily occurs at times when there is no direct surface run-off and when the permanent supply from ground water, lakes, or storage reservoirs is at a minimum.

The presence of snow with low temperature effectively cuts off direct surface inflow in winter, sometimes for a period of several months. Careful studies of the laws of supply to a stream from ground water during either summer or winter droughts will be of value in estimating the winter regimen.

With present knowledge it is evident that actual measurements of flow from gagings are even more needful in winter for the determination of available water supply from streams than in summer, although in the existing data of stream flow the winter period is to a considerable extent neglected.

WINTER RECORDS.

Data on open-water and winter conditions and the discharge measurements made during the frozen season are here given for the following stations:

Catskill Creek at South Cairo, N. Y.
Connecticut River at Orford, N. H.
Esopus Creek at Kingston, N. Y.
Fish River at Wallagrass, Me.
Kennebec River at North Anson, Me.
Rondout Creek at Rosendale, N. Y.
Wallkill River at Newpaltz, N. Y.
Winooski River at Richmond, Vt.

CONDITIONS AT STATIONS.

CATSKILL CREEK AT SOUTH CAIRO, N. Y.

This station was established July 4, 1901. It is located at the highway bridge in the village of South Cairo, about 1 mile north of the Catskill Mountain Railroad station for that place. The drainage area

is 263 square miles. Measurements are made from the downstream side of the bridge at ordinary and high stages, and by wading a short distance above the bridge at low stages.

The drainage basin of this stream receives the run-off from the north slope of the Catskill Range and lies for the most part in the timbered highlands of Greene County. The source of the creek is in a swamp at Franklinton, Schoharie County. It enters Hudson River at Catskill after traversing Greene County for nearly 25 miles. The stream flows over a rocky bed through the greater part of its course, having a total fall of 1,200 feet. At the station the bed consists of gravel and rock, the main channel lying nearest the right-hand abutment of the bridge, which has a clear span of about 194 feet. About two-thirds of the way across is a gravel bar covered with brush which affects the discharge to some extent in high water and at low-water stages rapids about 1,800 feet below the bridge tend to cause slack water at the regular section for gaging. Both banks are high and not subject to overflow. The left bank is wooded; the right is rocky and abrupt. Below the bridge the stream is fairly straight for about 1,000 feet; it then curves to the left and flows over some rifts, which at ordinary stages narrow the stream from about 200 to about 30 feet. Above the bridge the course is straight for about 500 feet; there is then a slight turn and some rapids that narrow the channel down to 80 or 90 feet, the width at the bridge being about 125 feet. A portion of the stream bed is permanent, the gravel bar on the left-hand side having a tendency to shift.

From Hudson River to the mouth of Kaaterskill Creek, about 2 miles, there is practically no velocity. From Kaaterskill Creek to Leeds, 3 miles farther up, Catskill Creek flows through a gorge of bluestone, in which it has a fall of about 180 feet. Two dams formerly utilized a portion of this head at Leeds. There is no interference at the station, however, as it is about 3 miles farther up. The extreme stages observed are as follows:

Extreme stages observed on Catskill Creek at South Cairo, N. Y.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	11.7	18,600
Low water	2.25	18
Extreme range	9.45	18,582

Catskill Creek in this vicinity usually freezes over about December 1, and the general breakup comes about March 1, the stream being partly free from ice for short periods in January or February during what is commonly known as the January thaw. The entire width is usually frozen from a point 500 feet above the station to a point about

1,500 feet below; the rapids seldom freeze except in the coldest weather. Needle ice is produced in abundance in this stream, the observer reporting that the channel is obstructed by this kind of ice for the greater part of the winter.

Ice conditions on Catskill Creek at South Cairo, N. Y.

SEASON OF 1903-4.

November 29, ice 0.6 foot; practically the same up to December 13.
December 17, ice at gage 0.88 foot.
December 19, ice at gage 1 foot.
December 20, rains; creek broken up.
December 27, ice at gage 0.25 foot.
December 31, ice at gage 0.6 foot.
January 1–22, ice averaged about 0.65 foot.
January 23–26, inclusive, ice broken up.
January 27 to February 8, ice from 0.1 to 0.6 foot thick.
February 9, heavy thaw; ice went out.
February 16 to March 3, ice from 0.2 to 1 foot thick.
March 8, heavy rains; ice went out.

SEASON OF 1904-5.

November 27, ice 0.1 foot thick.
December 1–7, ice 0.2 foot thick, increasing to 1 foot by December 27.
December 28, creek broken up.
January 5, creek filled with anchor ice.
January 7, anchor ice broken up.
January 15, creek filled with anchor ice.

January 25–28, ice 0.5 foot thick; stream frozen across to about same thickness both above and below gage. Observer states that stream is filled with anchor ice attached to bottom, except in narrow strip along gage. Conditions continued the same for three weeks with exception that general ice thickness increased from 1.2 feet upstream to 1.5 feet downstream from gage.

February 18, stream frozen over except along right bank, where ice becomes honeycombed and is broken.

February 25, stream frozen across both above and below gage 1.08 to 1.25 feet thick. Observer states that ice is gradually melting, and shows channel near left bank below gage.

March 4, ice throughout 0.83 to 1 foot thick, but narrow channel on each side.

March 19, ice broken up.

SEASON OF 1905-6.

December, some ice about the middle of the month, but river not frozen solid.
January 8, ice about 0.17 foot thick.
January 9–11, ice 0.25 foot thick.
January 12–14, ice 0.33 foot thick.
January 15, ice 0.25 foot thick
January 24, ice broken up.
February 1, about 0.83 foot of ice both above and below gage, also at gage.
February 22, ice broken up.
February 28, creek filled with anchor ice, both above and below gage.
March 5, ice went out about this date.

The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Catskill Creek at South Cairo, N. Y.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1901-2	2.90	4.82	1.92	1.37
1902-3	3.08	4.90	1.82	.16
1903-4	3.10	4.55	1.45	.54
1904-5	2.80	3.05	.25	.17
1905-6	2.70	5.15	2.45	.83

CONNECTICUT RIVER AT ORFORD, N. H.

This station was established August 6, 1900. It is located at the wooden highway bridge between Orford, N. H., and Fairlee, Vt. The drainage area at this point is 3,305 square miles. Measurements are made from the downstream side of the highway bridge.

The bed of the stream consists of gravel and is permanent. Both banks are high and do not overflow. At the bridge the channel is about 275 feet wide at ordinary stages and is broken by one pier. It is straight for 1,000 feet above the station and for a considerably longer distance below. The channel is about the same width both up and down stream, but at the bridge this width is cut down approximately 13 feet by the pier.

Several small streams enter the Connecticut near Orford, but the only stream of any considerable size is Waits River, about 5 or 6 miles above this point. The nearest dam is at Wilder, about 18 miles downstream. Backwater effect from this dam reaches probably within a few miles of Orford. Upstream the nearest dam is at East Ryegate, about 20 miles above Orford. There is considerable fall in the river in this 20-mile stretch, although it is somewhat concentrated at a few points. The extreme stages observed are as follows:

Extreme stages observed on Connecticut River at Orford, N. H.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	26.1	33,000
Low water	2.0	640
Extreme range	24.1	32,360

Connecticut River in this vicinity usually freezes over about December 1 and remains frozen until the middle or last of March. Near the bridge ice first forms at the shores and around the pier, the left channel always freezing over first and the right channel somewhat later. This portion of the river—from the dam at Wilder to quick water at or above Wells River—has usually a permanent ice cover during the winter months. Anchor or needle ice has never been found here in sufficient quantities to affect gage heights or interfere with gagings.

During the season of 1905–6 the river was completely frozen over at the Orford bridge only from about December 30 to January 24, when a rise in stage carried out the ice. It did not freeze entirely across again during the winter. An area about 1,000 feet long and 150 feet wide, nearly in the middle of the river and extending downward from the bridge, remained open.

Ordinary winter conditions are good at this station, and the range of gage heights is small. Occasionally a winter freshet such as those of December, 1901, and January, 1906, occurs, but these usually last only a few days. The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Connecticut River at Orford, N. H.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1900–1	5.8	9.0	3.2	....
1901–2	3.8	21.7	17.9	....
1902–3	6.6	8.8	2.2	....
1903–4	4.0	8.3	4.3	2.2
1904–5	4.0	4.5	0.5	2.2
1905–6	5.5	20.5	15.0	1.5

ESOPUS CREEK AT KINGSTON, N. Y.

This station was established July 5, 1901. It is located at the Washington Street Bridge, Kingston, N. Y., about 1 mile from the West Shore Railroad station. The measurements are made from the upstream side of a two-span highway bridge. The main span is about 117 feet wide. There is also a short span of about 19 feet on the left-hand end for extreme high water. The drainage area above this station is 324 square miles. The bed of the stream consists of earth and loose rock and is permanent. At ordinary stages the channel is from 90 to 110 feet wide at the bridge, but it is wider above and below. Upstream the channel is straight for about 300 feet. It then deflects slightly to the right. Downstream the channel is fairly straight for 700 or 800 feet. Rapids about 300 feet below affect the low-water

flow. Measurements can be made by wading above the Ulster and Delaware Railroad bridge, about 1 mile upstream. The right bank is of earth, of medium height and slightly wooded; it is not subject to overflow except at very high stages. The left bank is of ordinary height, slightly wooded, and subject to overflow in high water. The conditions are such that the overflow can be readily estimated.

Esopus Creek receives numerous small tributaries—mostly small torrential streams—which cause rapid fluctuations in the main streams. The stream channel is usually broad and shallow, the bed being covered with cobbles and small bowlders, until the vicinity of the gaging station is reached, when the slope is more gradual and the current less swift. At Olivebridge, about 20 miles above the station, there is a natural fall of about 22 feet that is increased to 28 feet by a timber dam on the crest of the ledge, and at Glenerie, where the West Shore Railroad crosses the Esopus, about 6 miles downstream, there is a cascade that has a fall of about 56 feet. The final descent to tidewater at Saugerties is made through a fall of 42 feet.

There are no dams in the vicinity of the gaging station, and the channel is unobstructed except by small rapids which affect the low-water flow only. The extreme stages observed are as follows:

Extreme stages observed on Esopus Creek at Kingston, N. Y.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	25.0	23,400
Low water	3.7	36
Extreme range	21.3	23,364

Esopus Creek in this vicinity usually freezes over about December 1, though the entire stream is not closed up. Ice generally forms first along the shore below the bridge and gradually works upstream, the velocity being swifter on the upstream side. The stream here has a wide range during the frozen season, the gage heights ranging from about 5 feet to 17 or 18 feet. These freshets sometimes occur as often as twice a month, and occasionally clear the creek of ice, this depending somewhat on the time of year and the thickness of the ice. The channel below the bridge sometimes becomes jammed, and in the spring it frequently has to be cleared out with dynamite. There is more or less open channel during the greater part of the winter at this station. Several ice measurements have been made here, and invariably there was a portion of the stream open. There are no reports or indications of needle ice, though it may form at times.

During 1901, 1902, and 1903 there was comparatively little ice in this stream, but in the winter of 1904–5 the ice had a thickness of

about 1.5 feet for a period of about six weeks, ranging from 0.1 to 0.2 feet at other times. The ice went out about March 18. The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Esopus Creek at Kingston, N. Y.

Date.	Gage height to water surface.			Maximum thicknes of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1901-2	5.28	9.95	4.67	0.36
1902-3	6.10	9.82	3.72	.43
1903-4	4.91	18.23	13.32	.80
1904-5	4.74	12.90	8.16	.71
1905-6	5.35	14.60	9.25	1.42

FISH RIVER AT WALLAGRASS, ME.

This station was established July 29, 1903. It is located just below the outlet of Wallagrass Brook. The drainage area at this point is 910 square miles. Measurements of the flow are made from a cable located about 1,500 feet downstream from the gage, and soundings are made on the line of the cable. The bed consists of gravel and is permanent. The banks are of medium height, but rarely overflow during high stages. The channel is straight for 500 feet above and 300 feet below the cable and is about 100 feet wide, being fairly uniform in cross-section near the station. Wallagrass Brook is the only stream of any considerable size entering Fish River in this vicinity. The gaging station is about 8 miles above the entrance of Fish River into the St. John and about 2 miles upstream from an undeveloped fall of about 20 feet. There are no dams in this vicinity. The extreme stages observed are as follows:

Extreme stages observed on Fish River at Wallagrass, Me.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	13.6	8,300
Low water	1.7	50
Extreme range	11.9	8,250

Fish River in this vicinity usually becomes frozen over about December 1 and remains so without interruption until about April 1. Ice forms first at the shores and gradually extends across the stream, with the exception that in the vicinity of the gage a small area remains open for a time. Occasionally during the winter the ice thins out, owing to the entrance of water from springs. Winter freshets are unusual in this vicinity. Winter conditions are very uniform, fluctuations in stage are usually slow, and the ice cover is

smooth and permanent, so that in general this station is especially favorable for records. The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Fish River at Wallagrass, Me.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1903-4	2.8	5.0	2.2	....
1904-5	3.3	5.2	1.9	1.9
1905-6	2.0	5.2	3.2	1.5

KENNEBEC RIVER AT NORTH ANSON, ME.

This station was established October 18, 1901. It is located $1\frac{1}{2}$ miles east of North Anson village and a short distance above the mouth of Carrabassett River. The drainage area at this point is 2,880 square miles. Measurements are ordinarily made from the covered wooden highway bridge, known locally as Patterson Bridge.

The bed of the stream is rocky, with stone and gravel in places, and is permanent. The right bank is high. The left bank is of medium height and is subject to overflow in times of highest water. At the bridge the channel is about 350 feet wide, broken by one pier. It is straight for about 100 feet upstream and 200 feet downstream from the bridge and is curved beyond these points. The channel widens out to about 500 feet a short distance up and down stream from the bridge.

Carrabassett River enters the Kennebec about 1 mile below Patterson Bridge, and at its mouth is a large island dividing the Kennebec into two narrow channels. The nearest dam is at Madison, 6 or 7 miles downstream, and backwater from this dam extends about to the mouth of Carrabassett River. Upstream the nearest dam is at Solon, about 8 miles above; the slope of the river in this portion at ordinary stages is in general about 4 feet to the mile, although it is concentrated somewhat at several points. At low water the velocity at the bridge becomes somewhat low and poorly distributed, and measurements have been made by means of a boat at a distance of about 1,000 feet downstream. The extreme stages observed are as follows:

Extreme stages observed on Kennebec River at North Anson, Me.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	14.95	39,000
Low water	1.55	800
Extreme range	13.40	38,200

Kennebec River in this vicinity usually becomes frozen over during the first week in December and remains so without interruption until about March 15 or April 15. Near the bridge ice first forms at the shores and around the piers and gradually extends, the channel being completely frozen over in a week or so in ordinary seasons. During the winter of 1905–6, however, narrow channels remained open in each span until about January 1, and narrow areas of open water remained somewhat after this date for short distances above and below the bridge.

In December there is probably considerable needle and anchor ice in the vicinity of the station, but after the ice becomes permanent no trouble has been occasioned from this source.

Ordinary winter conditions are good for recording gage heights at this station. The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Kennebec River at North Anson, Me.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
903–4	2.3	4.8	2.5	2.8
904–5	3.8	6.6	2.8	2.7
905–6	3.4	5.8	2.4	2.0

RONDOUT CREEK AT ROSENDALE, N. Y.

This station was established July 6, 1901. It is located at the highway bridge in Rosendale about one-half mile downstream from the Wallkill Valley Railroad station. The drainage area above this point is 380 square miles. There is some diversion through the Delaware and Hudson Company's canal, which is parallel to the river and is operated during the summer months from High Falls to tide water in Hudson River at the mouth of Rondout Creek. This canal receives its supply from Rondout Creek at High Falls, 3 miles upstream from Rosendale, but a large percentage of this diversion returns before reaching the gaging station. Observations made at Creeklocks of the stage of water in the canal and a record of the number of lockages afford sufficient data to estimate the flow through the canal. As the canal is closed during the winter months, it has no effect on the winter's record.

At the gaging station the bed of the stream consists of rock and is permanent. The channel at the bridge ranges from 90 to 135 feet in width and widens out considerably both above and below the bridge. It is straight for several hundred feet each way from the bridge, and some rifts about 1,000 feet downstream cause slack water at low

stages, when measurements are made at a ford about 1 mile below. Both banks are high and rocky and are not subject to overflow. Water passes under the bridge at all stages.

There is practically 75 feet fall from the diversion dam near High Falls, about 3 miles above the station, to the junction with Wallkill River, about 3 miles below. There are no streams of importance flowing into Rondout Creek in the neighborhood of Rosendale. The extreme stages observed are as follows:

Extreme stages observed on Rondout Creek at Rosendale, N. Y.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	19.40	18,130
Low water	6.00	50
Extreme range	13.40	18,080

Rondout Creek usually freezes over about December 1 and the ice goes out about March 1. There are usually two or three freshets during this period that break the ice up and in most cases carry it out.

The record was discontinued November 7, 1903, but started again about December 1, 1905, by the city of New York. The 1905–6 records show that the river was not closed by ice until about February 3 and that the ice went out February 22. The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Rondout Creek at Rosendale, N. Y.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1901–2	6.95	9.35	2.40	0.42
1902–3	6.95	9.85	3.10	.40
1905–6	5.04	5.60	.56	.46

WALLKILL RIVER AT NEWPALTZ, N. Y.

This station was established July 7, 1901, and was discontinued November 19, 1903. It was located at the highway bridge in Newpaltz, near the Wallkill Valley Railroad. The drainage area above this point is 736 square miles. The measurements were made from the downstream side of the highway bridge at all times except during extreme high water, when the Wallkill Valley Railroad bridge about 3 miles below was used. At low stages the water is rather slack and it is difficult to obtain a satisfactory measurement. The bed of the stream is composed of clay with large cobblestones and some bowlders,

and is permanent. Upstream the channel is straight for 400 or 500 feet; it then bends rather sharply to the right; downstream it is straight for several hundred feet. The right bank is rather high and slightly wooded, and does not overflow. The left bank is of medium height and is subject to overflow during high-water stages.

The principal tributary to the Wallkill in the vicinity of Newpaltz is the Shawangunk Kill, which enters near Gardiner, about 7 miles above, its total drainage area being 149 square miles. The dam nearest the station is at Walden, about 12 miles above. At low stages slight rapids about 300 feet below the bridge cause slack water in places and affect the discharge; at extreme high water a plain on the left side is overflowed, making it impossible to determine the flow at this point. The extreme stages observed were as follows:

Extreme stages observed on Wallkill River at Newpaltz, N. Y.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	24.8	24,480
Low water	5.5	105
Extreme range	19.3	24,375

While Wallkill River freezes more or less in December, there are no records that show the stream to be completely closed before January, and then only for short periods. Several discharge measurements under ice cover have been made, some showing backwater from ice and others giving fairly good results. In general, however, the river is partially open during the entire winter season, except in parts of January and February. The ice usually goes out about March 5.

Ice records on Wallkill River at Newpaltz, N. Y.

1902.

January 12, ice 1.2 feet thick.
January 19, ice 1.2 feet thick.
January 26, ice 1.2 feet thick.
February 2, ice 1.3 feet thick.
March 1, high water.

1903.

December 11, 1902, to January 4, ice about 0.5 foot thick.
January 4–17, ice 0.83 foot thick.
January 18–24, ice 0.92 foot thick.
January 25–31, ice 0.83 foot thick.
February 1–26, ice 1 foot thick.
February 28, ice went out under bridge.
March 1–4, ice 200 feet above and 300 feet below bridge.
March 5, river clear.

The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Wallkill River at Newpaltz, N. Y.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1901-2	7.20	18.50	11.30	1.25
1902-3	7.05	16.55	9.50	.82

WINOOSKI RIVER AT RICHMOND, VT.

This station was established June 25, 1903. It is located at the steel highway bridge about one-fourth mile from Richmond railway station on the road to Huntington. The drainage area at this point is 885 square miles. The bed consists of sand and gravel and is fairly permanent. The banks are fairly high, but overflow at extreme high water. The channel is slightly curved upstream, but straight for 1,000 feet or more downstream. It is about 175 feet wide at the bridge, and somewhat wider above and below. The nearest dam downstream is at Essex Junction, about 8 or 9 miles below the station, and there is a considerable amount of undeveloped fall between these two points. Upstream the nearest dam is at Bolton Falls, about 7 or 8 miles above the station. The extreme stages observed are as follows:

Extreme stages observed on Winooski River at Richmond, Vt.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	18.7	±19,000
Low water	3.7	139
Extreme range	15.0	±18,861

Winooski River in this vicinity usually freezes during the first part of December and remains frozen until about March 15. That part adjacent to and below the bridge, where the velocity is medium, freezes first. About one-fourth mile upstream, where a stretch of quick water begins, freezing takes place considerably later, and during some winters a permanent ice cover does not form here.

The contraction in the channel at the bridge tends to cause ice jams, and low velocity just below favors the formation of thick ice. During the January freshet of 1906 a jam affected gage readings during the remainder of the winter season. Pl. I, *B* (p. 24), shows the conditions at the gaging section March 9, 1906. The ice is extremely

rough, broken, and tilted, and the gage heights give no index whatever of the flow, which was confined to about one-third the ordinary width of channel. The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Winooski River at Richmond, Vt.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1903-4	4.15	6.7	3.55	2.75
1904-5	4.95	5.7	.75	3.05
1905-6	4.9	14.7	9.8	±2.5

Ordinary winter conditions are rather poor for estimates of flow at this station owing to the liability of unstable conditions. During low stages, which frequently occur in winter, the change in discharge is considerable for a slight difference in stage, and a slight change in the controlling ice conditions downstream may markedly affect the discharge:

GAGE HEIGHTS AND DISCHARGE MEASUREMENTS.

The following measurements have been made at the stations described above.

Stream measurements during frozen season.

CATSKILL CREEK AT SOUTH CAIRO, N. Y.

Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height—		Thickness of ice.	Snow on ice.	Gage height to water surface.		Gage height to bottom of ice.	
					To water surface.	To bottom of ice.			Discharge for open-water conditions.	Coefficient for reducing open water to ice conditions.	Discharge for open-water conditions.	Coefficient for reducing open water to ice conditions.
	Feet.	*Sq. ft.*	*Feet per sec.*	*Sec.-feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Sec.-feet.*		*Sec.-feet.*	
1901 December 9	*a* 65	106	1.03	110	3.30	2.93	0.37	......	120	0.92	66	1.67
1902 January 15	90	166	.89	148	3.50	2.84	.66	......	152	.97	53	2.79
1906 February 16	100	190	.33	62	2.82	2.22	.70	......	56	1.11	17	3.65

a Gaging made 70 yards below bridge.

Stream measurements during frozen season—Continued.

CONNECTICUT RIVER AT ORFORD, N. H.

Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height—To water surface.	Gage height—To bottom of ice.	Thickness of ice.	Snow on ice.	Gage height to water surface. Discharge for open-water conditions.	Gage height to water surface. Coefficient for reducing open-water to ice conditions.	Gage height to bottom of ice. Discharge for open-water conditions.	Gage height to bottom of ice. Coefficient for reducing open-water to ice conditions.
1903.	*Feet.*	*Sq. ft.*	*Feet per sec.*	*Sec.-feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Sec.-feet.*		*Sec.-feet.*	
January 24	276	1,760	1.69	2,970	7.33	6.00	......	......	4,925	0.61	3,470	0.86
January 29	273	1,610	1.63	2,620	6.71	5.40	......	......	4,240	.62	2,880	.91
January 29	273	1,620	1.66	2,690	6.75	5.50	......	......	4,285	.63	2,975	.90
January 30	276	1,760	1.69	2,980	7.30	6.00	......	......	4,890	.61	3,470	.86
February 7	278	1,810	1.65	2,990	7.38	6.05	......	......	4,980	.60	3,520	.85
February 7	278	1,810	1.67	3,030	7.40	6.05	......	......	5,000	.61	3,520	.86
1904.												
February 3	240	851	1.00	850	4.20	2.40	2.03	......	1,880	.45	815	1.04
February 3	241	847	.99	840	4.17	2.37	2.03	......	1,860	.45	801	1.05
February 4	239	804	.93	750	4.03	2.23	2.03	......	1,760	.43	738	1.02
February 4	236	804	.95	760	3.99	2.19	2.03	......	1,735	.44	720	1.05
February 5	235	813	93	760	4.03	2.23	2.03	......	1,760	.43	738	1.03
February 5	235	805	95	765	4.03	2.23	2.03	......	1,760	.43	738	1.04
1905.												
February 28	235	775	.88	686	4.07	2.30	2.01	0.1	1,790	.38	770	.89
March 1	235	794	.96	766	4.26	2.40	2.09	.1	1,925	.40	815	.94
March 1	235	794	.93	739	4.25	2.39	2.09	.1	1,918	.39	810	.91
1906.												
February 8	327	1,920	1.17	2,250	[illegible].84	5.51	1.48	.2	4,380	.51	2,980	.76
February 15	327	1,870	1.20	2,240	6.80	5.32	1.48	.9	4,340	.52	2,810	.80
February 17	327	1,790	1.14	2,040	6.56	5.06	1.52	.9	4,080	.50	2,570	.79
March 14	327	1,560	1.08	1,680	6.00	4.56	1.55	.1	3,470	.48	2,160	.78
March 15	327	1,440	1.04	1,490	5.59	4.15	1.55	.1	3,060	.49	1,840	.81

ESOPUS CREEK AT KINGSTON, N. Y.

Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height—To water surface.	Gage height—To bottom of ice.	Thickness of ice.	Snow on ice.	Gage height to water surface. Discharge for open-water conditions.	Gage height to water surface. Coefficient for reducing open-water to ice conditions.	Gage height to bottom of ice. Discharge for open-water conditions.	Gage height to bottom of ice. Coefficient for reducing open-water to ice conditions.
1901.												
December 4	86	280	0.84	236	5.28	5.20	0.083	......	329	0.72	309	0.76
1902.												
January 9 [a]	100	419	1.25	522	6.54	6.41	.13	......	716	.73	669	.78
February 28 [b]	116	706	2.39	1,690	9.14	8.94	.20	......	2,030	.83	1,900	.89
December 11	90	404	1.18	476	1.60	6.50	.10	......	741	.64	700	.68
December 1 [c]	116.6	1,170	2.96	3,460	13	......	......	......	5,300	.65	......	......
1903.												
January 14 [d]	101.6	413	1.03	425	6.9	6.32	.58	......	864	.49	638	.67
February 24 [e]	104.6	443	1.47	654	7.1	6.70	.40	......	950	.69	782	.84
1906.												
February 15	90	287	.87	250	5.60	5.17	.33	......	412	.61	302	.83

FISH RIVER AT WALLAGRASS ME.

Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height—To water surface.	Gage height—To bottom of ice.	Thickness of ice.	Snow on ice.	Gage height to water surface. Discharge for open-water conditions.	Gage height to water surface. Coefficient for reducing open-water to ice conditions.	Gage height to bottom of ice. Discharge for open-water conditions.	Gage height to bottom of ice. Coefficient for reducing open-water to ice conditions.
1906.												
February 15	95	205	0.95	195	3.91	2.66	1.25	0.65	620	0.32	225	0.87
Do	95	205	.96	196	3.91	2.66	1.25	.65	620	.32	225	.87
March 15	115	312	1.21	378	4.99	3.83	1.20	.9	1,080	.35	580	.65
Do	115	319	1.22	390	5.08	3.92	1.20	.9	1,125	.35	620	.63

[a] Partly frozen over; stations 20–70 and 110–115 open.
[b] Partly frozen over; stations 0–25 and 110–116 open.
[c] River frozen over 150 feet below bridge and 200 feet above. Measurements taken at 0.6 depth. No ice at bridge.
[d] Stations 15–40 river open.
[e] Stations 12–40 river open; ice rough.

NOTE.—February 8 and 17, river partly open for a short distance below bridge. March 14 and 15, river partly open for a short distance below bridge, but not as much as on February 17.

Stream measurements during frozen season—Continued.

KENNEBEC RIVER AT NORTH ANSON, ME.

Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height— To water surface.	Gage height— To bottom of ice.	Thickness of ice.	Snow on ice.	Gage height to water surface. Discharge for open-water conditions.	Gage height to water surface. Coefficient for reducing open-water to ice conditions.	Gage height to bottom of ice. Discharge for open-water conditions.	Gage height to bottom of ice. Coefficient for reducing open-water to ice conditions.
	Feet.	*Sq. ft.*	*Feet per sec.*	*Sec.-feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Sec.-feet.*		*Sec.-feet.*	
1904.												
January 27	240	393	1.90	749	3.40	1.55	1.8	2.0	3,170	0.24	±675	±1.11
January 28	240	398	1.97	786	3.40	1.55	1.8	2.0	3,170	.25	±675	±1.16
March 2	230	285	1.86	529	3.55	1.45	2.1	......	3,450	.15	±600	± .88
March 4	230	285	2.01	572	3.65	1.55	2.1	......	3,650	.16	±675	± .85
1905.												
February 9	458	1,390	1.50	2,080	5.27	3.27	2.10	1.0	7,530	.28	2,920	.71
Do	458	1,390	1.54	2,140	5.32	3.32	2.10	1.0	7,680	.28	3,020	.71
1906.												
January 9 [a]	440	1,100	1.17	1,290	3.58	2.38	1.28	.1	3,520	.37	1,550	.83
January 10 [a]	440	1,030	1.09	1,120	3.40	2.22	1.30	.1	3,170	.35	1,370	.82
March 2	445	1,140	1.40	1,590	4.26	2.43	1.97	.1	4,980	.32	1,630	.98
March 3	445	1,050	1.31	1,380	4.08	2.27	1.98	.1	4,580	.30	1,420	.97
March 30	447	1,180	1.36	1,600	4.77	2.67	2.26	.0	6,220	.26	1,950	.82
Do	447	1,200	1.38	1,660	4.80	2.70	2.26	.0	6,300	.26	1,990	.83
April 11 [b]	450	1,210	1.37	1,660	4.70	2.80	1.95	±1.0	6,050	.28	2,140	.79
Do. [b]	450	1,240	1.38	1,710	4.70	2.80	1.95	±1.0	6,050	.28	2,140	.80

RONDOUT CREEK AT ROSENDALE, N. Y.

1901.												
December 6 [c]	104	479	0.46	222	6.80	6.-1	0.26	......	415	0.53	253	0.88
1902.												
January 14	105	479	.88	423	7.00	6.53	.47	......	540	.78	247	1.71
February 8	102	732	1.62	732	8.81	8.41	.40	......	2,330	.31	1,900	.40
February 26	80	489	1.11	543	8.13	6.71	1.42	......	1,610	.34	359	1.51
Do	100	517	1.32	684	8.43	7.01	[d]1.42	......	1,930	.35	549	1.24
1903.												
February 25	115	474	1.6	676	7.9	7.40	.50	......	4,370	.15	885	.76
1906.												
February 27	117	555	.35	194	[e]5.15	4.51	.46	......	......	......	......	......

WALLKILL RIVER AT NEWPALTZ, N. Y.

1901.												
December 11 [f]	135	1,310	2.32	3,040	11.50	10.8	0.70	......	3,830	0.79	3,250	0.94
1902.												
January 21	80	423	.78	332	7.24	6.04	1.20	......	860	.39	277	1.20
January 23 [g]	140	1,880	3.22	6,060	17.33	16.41	.92	......	9,290	.65	8,300	.73
January 31 [h]	100	679	1.72	1,170	9.07	8.07	1.00	......	1,980	.59	1,330	.88
February 10	115	496	1.20	597	7.78	6.78	1.00	......	1,160	.51	619	.97
February 24	85	388	.74	288	7.35	[i]5.25	2.10	......	919	.31	......	......
1903.												
February 7	140	1,070	2.14	2,290	11.2	10.45	.75	......	3,580	.64	2,970	.77
February 10 [j]	142	999	2.03	2,030	10.9	9.73	1.17	......	3,330	.61	2,440	.83
February 26	130	757	1.24	945	8.85	7.89	.96	......	1,830	.52	1,230	.77

[a] Frozen except for narrow channels above and below bridge.
[b] Frozen except for narrow channel near left bank.
[c] Ice varied from one-half inch to 5 inches from bank to bank at riff just below; ice extended one-third way across.
[d] Estimated from previous measurements, same date.
[e] Subject to correction.
[f] Ice cover from stations 40-85.
[g] Ice badly broken at station 20.
[h] Ice badly broken at station 110.
[i] Below rating table; water considerably above top of ice.
[j] Stations 135-142 open.

Stream measurements during frozen season—Continued.

WINOOSKI RIVER AT RICHMOND, VT.

Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height: To water surface.	Gage height: To bottom of ice.	Thickness of ice.	Snow on ice.	Gage height to water surface: Discharge for open-water conditions.	Gage height to water surface: Coefficient for reducing open-water to ice conditions.	Gage height to bottom of ice: Discharge for open-water conditions.	Gage height to bottom of ice: Coefficient for reducing open-water to ice conditions.
	Feet.	*Sq. ft.*	*Feet per sec.*	*Sec.-feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Sec.-feet.*		*Sec.-feet.*	
1905.												
March 3	75	109	1.89	206	5.45	2.70	2.95	0	1,460	0.14	....	....
March 4	75	114	2.30	262	5.58	2.83	2.95	0	1,610	.16	....	....
1906.												
March 9[a]	70	348	1.68	585	5.62	±3.4	±2.8	0	1,650	.35	....	....

[a] Channel open 1,000 feet upstream and one-half mile downstream. Ice very rough, broken, and tilted, reaching to bottom for about two-thirds of section.

The following table includes some single sets of discharge measurements, with a brief description of the conditions. As a rule, these are insufficient in range at a given station to give much information regarding the winter rating curve.

Single discharge measurements on frozen streams, 1906.

River and station.	Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height— To water surface.	Gage height— To bottom of ice.	Thickness of ice.	Gage height to water surface. Discharge for open-water conditions.	Gage height to water surface. Coefficient for reducing open water to ice conditions.	Gage height to bottom of ice. Discharge for open-water conditions.	Gage height to bottom of ice. Coefficient for reducing open water to ice conditions.
	1906.	*Feet.*	*Square feet.*	*Feet per second.*	*Second-feet.*	*Feet.*	*Feet.*	*Feet.*	*Second-feet.*		*Second-feet.*	
Chemung, Chemung, N. Y.[a]	February 17	225	1,040	0.65	674	2.85	2.42	0.53	808	.83	510	1.32
Chippewa, Eau Claire, Wis.[b]	January 25	332	2,772	1.00	2,761	4.82	4.10	.80	3,555	.78	2,010	1.37
Des Moines, Keosaqua Iowa[c]	January 13	565	1,984	1.13	2,260	2.45	2.06	.54	4,415	.51	3,450	.66
Flambeau, Ladysmith, Wis.[d]	January 26	344	501	1.23	632	16.13	15.18	1.20	1,650	.38	730	.87
Genesee, Jones Bridge, Mount Morris, N. Y.[e]	February 12	118	298	1.52	452	5.75	5.36	.49	830	.54	654	.69
Do.[e]	February 13	118	290	1.65	479	5.78	5.47	.41	841	.57	709	.68
Do[f]	February 16	127	373	1.40	525	6.00	5.42	.68	942	.56	687	.76
Genesee, Rochester, N Y.[g]	February 14	306	1,710	.43	728	1.40	1.00	.50	916	.79	300	2.43
Do.[h]	February 15	360	1,020	.88	894	1.53	1.17	.46	1,110	.80	570	1.57
Hoosic, Buskirk, N. Y.[i]	February 10	130	576	1.23	709	3.90	3.26	.54	1,920	.37	1,260	.56
Maumee, Sherwood, Ohio[j]	February 11	236	597	.77	458	3.34	2.81	.58	886	.52	566	.81
Otter Creek, Middlebury, Vt.[k]	March 10	106	352	3.30	1,160	13.40	12.77	.70	1,360	.85	850	1.37
Raquette, Massena Springs, N. Y.[l]	March 28	174	1,710	3.14	5,370	10.31	8.64	1.92	....	....	....	....
Do.[l]	March 29	172.6	1,540	3.07	4,710	8.77	7.45	1.62	....	....	....	....
Do.[m]	March 30	172.5	1,740	3.57	6,220	9.73	8.65	1.28	....	....	....	....
West Canada Creek, Twin Rock Bridge, N. Y.[n]	February 9-10	175	527	.78	412	3.02	1.84	1.35	1,830	.22	860	.48

[a] Gravel bed; under ice surface smooth; considerable needle ice.
[b] Gravel bed; open 70 feet wide upstream for a long distance; same for about 1,000 feet downstream; then frozen for about 600 feet; then open for a long distance.
[c] Gravel bed; ice rough.
[d] Coarse gravel.
[e] Gravel and sand bed.
[f] Measurements made about 250 feet downstream from regular station.
[g] Gravel bed.
[h] Elmwood Avenue Bridge (regular station); ice smooth on bottom; some needle ice running at stations 100-140.
[i] Considerable needle ice; gravel bed.
[j] Gravel bed; ice rough.
[k] Sand and gravel bed; river open 500 feet below gage for about 800 feet to dam and arch bridge where gaging was made.
[l] Gravel bed; river open, stations 150-175.
[m] River open, stations 0-35 and 130-175.
[n] Gravel bed; under ice surface nearly smooth; a little needle ice.

STATION RATING CURVES FOR ICE COVER.

GENERAL CONSIDERATIONS.

At several stations sufficient data have been gathered to construct a rating curve for conditions of ice cover, applicable to average ice conditions within the range of winter gage heights, but the variation in form of curve with change in thickness of ice is still uncertain, and the proper rating curve or coefficient to apply for the time when the ice is thin has not been sufficiently verified by gagings. A station rating curve for conditions of ice cover must evidently be constructed on one of the following bases: (1) Gage heights to the surface of the water as determined from a hole cut in the ice, or (2) gage heights to the bottom of the ice.

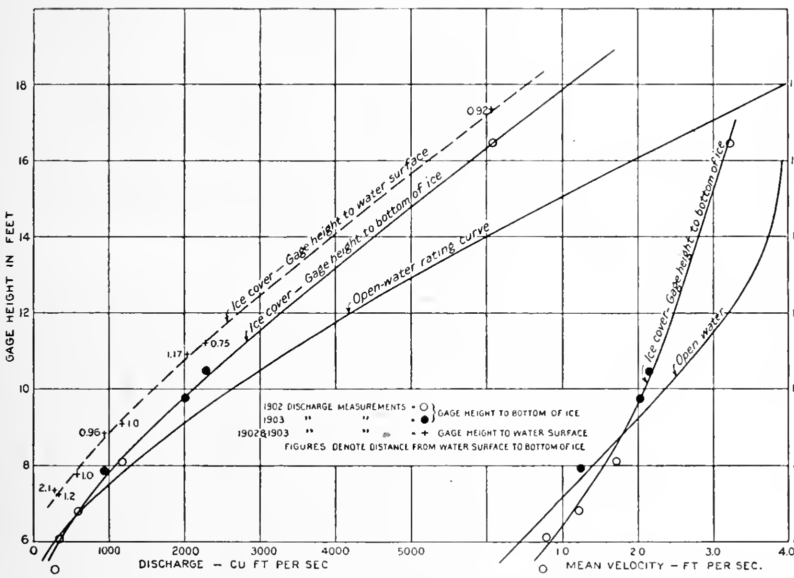


FIG. 4.—Rating and velocity curves under ice cover, Wallkill River at Newpaltz, N. Y.

In figs. 4 to 6 are shown the results of such gagings as have been made under ice cover at three gaging stations, the gage heights being plotted in each of the above ways and the open-water rating curve being shown for comparison.

WALLKILL RIVER AT NEWPALTZ, N. Y.

So far as can be determined at present, the rating curve based on gage heights to the water surface seems to give the best results; that is, the points lie more nearly on a smooth curve (fig. 4). There is no great difference, however, except in the case of the lowest gaging, in which the thickness of the ice was perhaps only half of the

distance, 2.1 feet, from the water surface to the bottom of the ice, indicating that the water below the ice was under some pressure. It will be noticed that the range in ice thickness is not large.

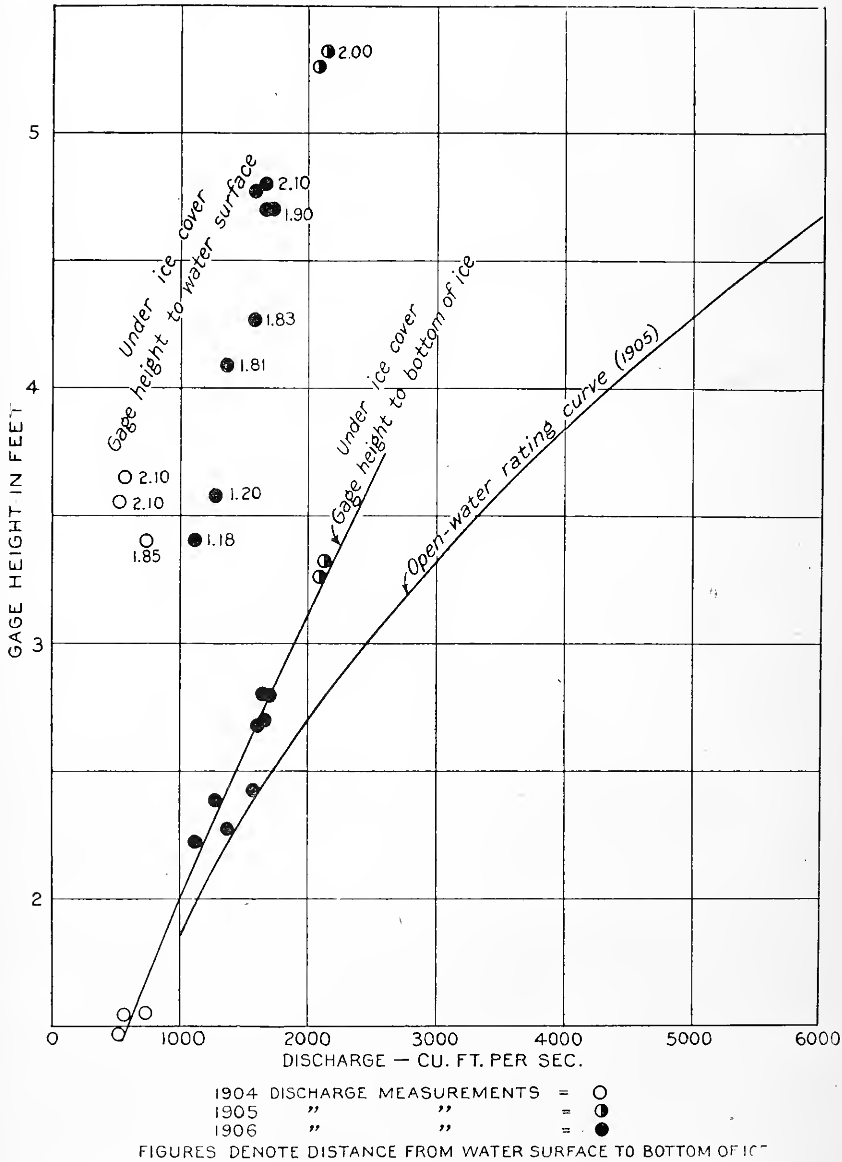


FIG. 5.—Rating curve under ice cover, Kennebec River at North Anson Me.

KENNEBEC RIVER AT NORTH ANSON, ME.

The effect of varying thickness of ice on discharge for a given gage height is clearly shown (fig. 5). No one curve can be drawn through the points plotted for the gage heights to the water surface, although a few

more gagings would, perhaps, enable a series of curves to be drawn for different distances from the water surface to the bottom of the ice. It is preferable to use these distances rather than thickness of the ice, for the position of the bottom of the ice with reference to the water surface is not only dependent on the ice thickness (in general being about 92 per cent of it), but will also vary with the

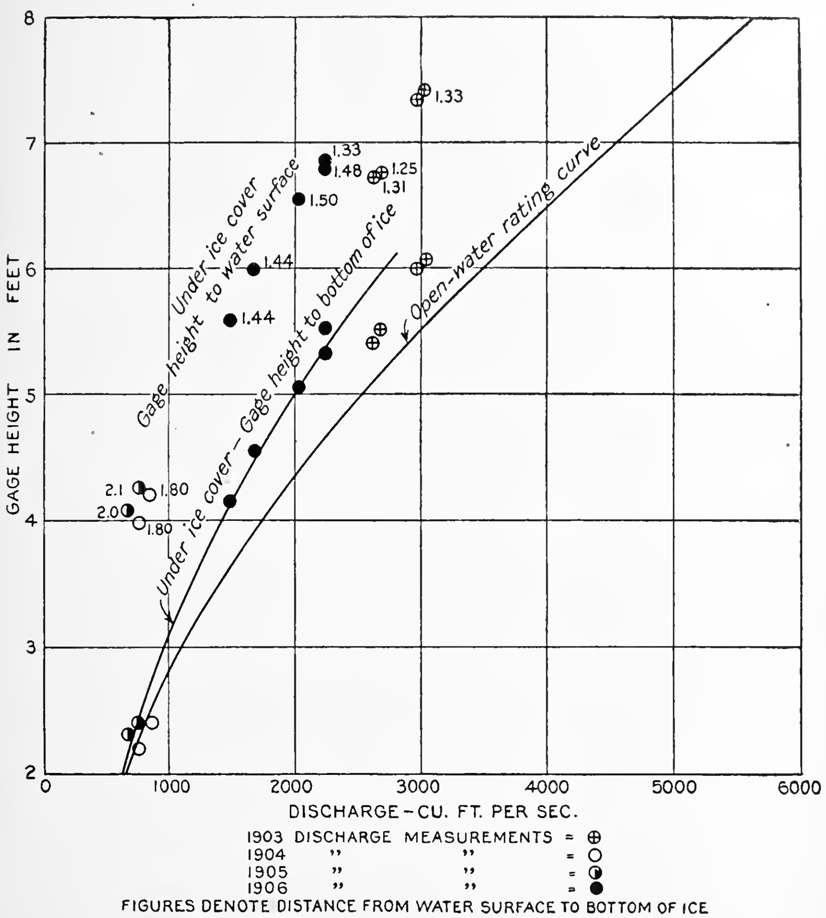


FIG. 6.—Rating curve under ice cover, Connecticut River at Orford, N. H.

snow load and thus include its effect. If gage heights to the bottom of the ice are used a fairly consistent curve is obtained for this station.

CONNECTICUT RIVER AT ORFORD, N. H.

The same general results appear here as in the case of the Kennebec, although the range of ice thickness is less (fig. 6). The gagings of 1903 and 1904 are open to some question, owing to the manner in

which they were made, and have been given little weight in drawing the curve as shown.

GENERAL FORM OF RATING CURVE FOR ICE COVER.

The curve, as constructed with gage heights to the bottom of the ice, in general lies to the left of the open-water rating curve, but tends to approach it in its lower portion and perhaps to cross it.

The degree of curvature of the two curves is in general about the same in their lower parts and, like the open-water curve, the rating curve for ice cover is apparently a tangent in its upper part. In fact, it will be noticed in the case of the Wallkill and Connecticut that the ice-cover curve will be approximately the same as the open-water curve if the latter is swung around the intersection point of the two curves until the upper parts coincide.

With gage heights to the surface of the water, the indications are that the curve for ice cover (or rather the series of curves constructed for different thicknesses of ice) will be approximately parallel to the curve determined by gage heights to the bottom of the ice.

RELATION BETWEEN DISCHARGE UNDER ICE COVER AND FOR OPEN SECTION.

If gage heights are taken to the bottom of the ice and the discharge compared with that for the same gage heights in open channel, it is found that as the stage increases this ratio decreases. In the case of the Wallkill, this ratio is greater than unity below about gage height 6.8, where the curves cross, and decreases from this point to a value of about 0.71 at gage height 18.0. With the Connecticut the range in this ratio is from 0.97 at gage height 2.0 to 0.78 at gage height 6.0. Evidently no mean value of the ratio can be assumed that will give anything more than rough results.

It is not deemed wise in the light of existing data to advise the use of either one of the above-described methods for the construction of rating curves to the exclusion of the other, although the indication seems to be that the use of gage heights to the bottom of the ice will prove most generally convenient. There will undoubtedly be cases, however, where this method must be used with caution, more especially in the lower part of the curve, as it would not take into account the effect of ice being held down by shores or piers, and the consequent pressure or head under which flow was taking place.

VERTICAL VELOCITY MEASUREMENTS UNDER ICE COVER.

DETAILS OF VERTICAL VELOCITY CURVES.

The principal data for vertical velocity curves at 25 stations are given on the following pages. It will be noted that each curve can be replotted from the table, if desired. In general, mean results are given for each set of curves taken, but some sets are subdivided in order to separate different conditions.

Vertical velocity measurements.

CATSKILL CREEK AT SOUTH CAIRO, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 16	2.82		25	4.0	3.1	1.00	0.37	0.43	0.50	0.28	0.39	0.30	0.14	0.51	0.1	0.03	2.0	0.64	0.8	0.27	0.72	0.86	0.95
			55	3.6	2.7	1.00	.41	.47	.60	.24	.42	.50	.10	.60			1.6	.59	.4	.16	.69	.88	.98
			60	3.6	2.7	1.00	.48	.53	.52	.44	.48	.32	.35	.55	.3	.10	1.8	.67	.8	.31	.87	.90	.99
			65	3.3	2.4	.95	.51	.56	.50	.52	.51	.25	.48	.55	.3	.12	2.2	.90	1.2	.49	.92	.91	1.00
Mean of 4 curves				3.6	2.7	.98	.44									.06		.70		.31	.80	.88	.98

CHEMUNG RIVER AT CHEMUNG, N. Y.[b]

Date.	Gage height to water surface.	Gage height to bottom of ice	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Max. thread In feet.	In per cent of depth.	Coeff. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.																							
February 17[c]	2.85	3.27	29	9.2	8.8	0.50	0.39	0.50	0.43	0.40	0.42	0.20	0.06	0.50	1.2	0.14	7.6	0.86	3.6	0.41	0.78	0.78	0.93
			39	10.2	9.8	.50	.56	.79	.74	.45	.60	0	.15	.85	1.0	.10	6.7	.68	3.3	.34	.66	.71	.93
			50	10.6	10.2	.45	.93	1.38	.58	1.42	1.00	0	.61	1.70	2.9	.28	8.5	.83	6.0	.58	.54	.67	.93
			60	9.1	8.9	.30	1.06	1.86	1.26	1.30	1.28	0	.40	1.86	1.0	.11	6.2	.70	3.4	.38	.57	.57	.83
			80	6.5	6.3	.30	.89	2.12	1.55	1.70	1.62	0	1.20	2.13	.4	.07			1.8	.29	.42	.42	.55
			90	6.5	6.2	.40	.66	1.54	.70	.66	.68	0	.45	1.72	.6	.10	3.5	.56	2.1	.34	.38	.43	.96
			100	6.2	5.8	.45	.36	1.26	1.05	.86	.96	0	.26	1.28	.1	.02	2.0	.34	1.0	.16	.28	.29	.38
			110	5.9	5.6	.45	.36	.73	.50	.52	.51	0	.18	.74	.3	.05	3.5	.63	2.0	.36	.49	.50	.71
Mean of 8 curves				8.0	7.7	.42	.65									.11		.58		.36	.52	.55	.78
February 17	2.85	3.38	120	5.1	4.8	.40	.34	.40	.36	.34	.35	.32	.14	.39	.6	.13	3.9	.82	2.4	.51	.86	.84	.97
			130	4.0	3.6	.50	.67	.74	.71	.61	.66	.60	.49	.75	.3	.08	2.5	.69	1.4	.39	.90	.90	1.02
			140	3.6	3.2	.50	.74	.90	.72	.67	.70	.35	.45	.90	.6	.18	2.4	.75	1.4	.44	.82	.82	1.07
			150	3.7	3.2	.60	.80	.95	.75	.85	.80	.48	.74	.94	.8	.24	2.9	.91	1.6	.50	.85	.84	1.00
Mean of 4 curves				4.1	3.7	.51	.64									.16		.79		.46	.86	.85	1.02

[a] Gravel bed.

[b] Coarse gravel bed.

[c] Needle ice from 1 to 4 feet in depth under bottom of ice.

Vertical velocity measurements—Continued.

CHIPPEWA RIVER AT EAU CLAIRE, WIS.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves: Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity, Upper: In feet.	Upper: In per cent of depth.	Lower: In feet.	Lower: In per cent of depth.	Depth of thread of maximum velocity: In feet.	In per cent of depth.	Coefficients for reducing to mean velocity: Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
1906.																							
January 25	4.82	3.92	130	14.3	13.2	1.10	0.52	0.72	0.53	0.47	0.50	0.18	0.13	0.73	2.6	0.19	10.4	0.77	6.2	0.47	0.71	0.72	1.04
			150	13.5	12.4	1.10	.76	.90	.67	.83	.75	.39	.58	.92	3.6	.28	11.3	.91	7.8	.63	.83	.84	1.01
			170	12.6	11.5	1.10	1.14	1 38	1.10	1 18	1.14	.40	.54	1.39	2.7	.22	10.0	.83	6.5	.57	.82	.83	1.00
Mean of 3 curves				13.5	12.4	1.10	.81									.23		.84		.56	.79	.80	1.02

CONNECTICUT RIVER AT ORFORD, N. H.[b]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper: In feet.	Upper: In per cent of depth.	Lower: In feet.	Lower: In per cent of depth.	Max. thread: In feet.	In per cent of depth.	Coef.: Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1903.																							
January 29	6.71	5.40	150		6.6		1.92	2.17	2.23	1.65	1.94	1.22	1.08	2.27	0.5	0.08	4.5	0.68	2.0	0.30	0.84	0.88	0.99
	6.75	5.50	280		9.8		1.94	2.12	2.15	1.82	1.98	1.13	1.32	2.21	1.0	.10	7.0	.71	3.0	.31	.88	.92	.98
January 30	7.30	6.00	340		6.2		1.85	1.96	1.92	1.86	1.89	1.22	1.58	1.97	.8	.13	5.0	.81	2.5	.40	.94	.94	.98
February 7	7.38	6.05	90		7.7		1.58	1.91	1.56	1 62	1.59	.76	.85	1.91	1.7	.22	6.2	.81	3.8	.49	.83	.83	1.00
January 30	7.30	6.00	100		6.3		1.73	1.93	1.92	1.53	1.72	1.15	1.19	2.00	6	.10	4.2	.66	2.3	.37	.86	.90	1 00
February 7	7.38	6.05	110		7.2		1.76	1.99	1.94	1.60	1.77	1.22	1.05	2.04	.6	.08	5.1	.71	2.7	.37	.86	.88	1.00
Mean of 6 curves					7.3		1.80									.12		.73		.37	.87	.89	.99
1904.																							
February 1	4.15	2.45	130	3.8	2.0	2.00	.67	.72	.86	.52	.69	.50	.33	.87	.1	.05	1.2	.60	.3	.15	.77	.93	.97
			140	3.9	2.1	2.00	.40	.42	.60	.22	.41	.48	.00	.61			1.2	.57	.3	.14	.66	.95	.97
			150	5.3	3.5	2.00	1.23	1.33	1.48	1.00	1.24	1.09	.70	1.48	.1	.03	2.4	.68	.7	.20	.83	.92	1.00
February 2	3.95	2.25	250	7.7	6.0	2.00	1.04	1.10	1.21	.92	1.06	.80	.61	1.21	.3	.05	3.5	.58	1.3	.22	.86	.95	.98
			260	8.2	6.5	1.85	1.03	1.13	1.16	.92	1.04	.74	.52	1.18	.3	.05	4.2	.65	2.0	.31	.87	.91	.99
			270	8.1	6.4	1.95	1.11	1.17	1.20	1.03	1.12	.93	.82	1.22	.5	.08	4.3	.67	1.9	.30	.91	.95	1.00
			280	7.4	5,8	1.85	1.10	1.20	1.22	.98	1.10	.85	.70	1.23	.3	.06	3.9	.67	1.8	.31	.89	.92	1.00
February 3	4.17	2.37	200	5.0	3.0	2.25	.61	.66	.78	.43	.60	.55	.20	.78	.2	.06	1.8	.60	.4	.13	.78	.92	1.00
February 4	4.03	2.22	110	4.8	3.3	1.70	1.12	1.20	1.32	.92	1.12	1.13	.68	1.32			2.0	.60	.8	.24	.85	.93	1.00

[a] Gravel bed.

[b] Gravel and sand bed.

Vertical velocity measurements—Continued.

CONNECTICUT RIVER AT ORFORD, N. H.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.		In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.					
1904.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 5	4.03	2.23	90	5.2	3.6	1.75	0.93	1.03	1.05	0.82	0.94	0.92	0.34	1.06	0.5	0.11	2.2	0.61	1.3	0.36	0.88	0.90	1.00
			100	4.2	2.4	1.95	.96	1.06	1.15	.78	.96	.90	.45	1.15	.4	.17	1.5	.63	.6	.25	.83	.90	1.00
			340	5.3	4.2	1.60	.85	1.02	.98	.77	.88	.83	.00	1.02	.5	.12	2.9	.69	1.7	.40	.83	.83	.97
Mean of 12 curves				5.7	4.1	1.91	.92									.07		.63		.25	.83	.92	.99
1905.																							
February 28	4.07	2.25	100	4.2	3.1	1.3	1.00	1.13	1.00	.98	.99	.58	.80	1.15	.6	.19	2.3	.75	1.2	.39	.87	.88	1.00
			110	5.0	3.5	1.8	.88	1.02	1.02	.74	.88	.40	.40	1.07	.4	.11	2.3	.66	1.2	.34	.82	.86	1.00
			120	5.5	3.9	1.8	1.24	1.32	1.36	1.14	1.25	1.00	.93	1.38	.2	.05	2.5	.64	1.1	.28	.90	.94	.99
			150	5.2	3.5	1.9	1.12	1.27	1.34	.89	1.12	1.05	.57	1.37	.2	.06	2.2	.63	1.2	.34	.82	.88	1.00
			170	5.5	3.7	2.0	1.15	1.23	1.32	.99	1.16	.85	.75	1.33	.2	.05	2.3	.62	.9	.24	.86	.94	1.00
			190	5.0	3.2	2.1	.93	1.04	1.10	.77	.94	.73	.40	1.11	.1	.03	2.1	.66	.8	.25	.84	.89	.99
			240	5.8	3.6	2.5	.69	.87	.71	.63	.67	.33	.38	.88	.7	.19	2.7	.75	1.6	.45	.78	.79	1.03
			260	6.7	4.7	2.3	1.13	1.28	1.10	1.16	1.13	.87	.60	1.29	1.0	.21	3.7	.79	2.7	.57	.88	.88	1.00
			280	6.7	5.1	1.9	1.19	1.33	1.25	1.13	1.19	.83	.85	1.35	.8	.16	3.7	.73	2.0	.39	.88	.90	1.00
			330	5.5	3.9	2.0	.92	1.13	.97	.82	.90	.30	.60	1.22	.7	.18	2.8	.72	1.4	.36	.75	.81	1.02
Mean of 10 curves				5.5	3.8	1.96	1.02									.12		.70		.36	.84	.88	1.00
March 1	4.26	2.40	110	5.2	3.6	1.8	1.08	1.25	1.23	.88	1.06	92	.48	1.32	.3	.08	2.3	.64	1.3	.36	.82	.86	1.02
			160	5.7	4.0	1.9	1.28	1.48	1.39	1.15	1.27	1.00	.72	1.53	.6	.15	2.8	.70	1.6	.40	.84	.86	1.01
			180	5.7	3.9	2.1	1.14	1.36	1.33	.97	1.15	.62	.23	1.41	.3	.08	2.7	.69	1.4	.36	.81	.84	.99
			200	4.5	2.2	2.6	.76	.83	.80	.72	.76	.56	.56	.83	.2	.09	1.6	.73	.9	.41	.92	92	1.00
			250	7.3	5.3	2.3	.94	.96	1.07	.85	.96	.88	.72	1.07	.2	.04	2.9	.55	1.0	.19	.88	.98	.98
			270	7.1	5.2	2.2	1.25	1.37	1.32	1.18	1.25	1.00	.92	1.38	.6	.12	3.7	.71	2.1	.40	.91	.91	1.00
			320	5.5	3.8	1.8	1.14	1.32	1.27	1.01	1.14	.93	.55	1.33	.4	.10	2.7	.71	1.7	.45	.86	.86	1.00
			340	5.6	4.8	1.1	.92	1.12	1.04	.78	.91	.61	.35	1.13	.6	.12	3.4	.71	2.0	.42	.81	.82	1.01
Mean of 8 curves				5.8	4.1	1.98	1.06									.10		.68		.37	.86	.88	1.00

Vertical velocity measurements—Continued.

CONNECTICUT RIVER AT ORFORD, N. H.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 8 [a]	6.84	5.51	60	5.9	4.6	1.45	0.95	1.03	1.09	0.85	0.97	0.89	0.34	1.10	0.1	0.02	3.0	0.67	1.1	0.25	0.86	0.92	0.97
			140	7.7	5.6	2.15	1.58	1.89	1.42	1.62	1.52	1.00	1.14	1.95	1.6	.29	4.6	.81	3.4	.59	.81	.84	1.04
			180	7.2	6.1	1.20	1.67	1.86	1.87	1.53	1.70	1.44	.80	1.92	.6	.09	4.4	.72	1.8	.29	.87	.90	.98
			220	7.2	6.0	1.30	1.44	1.63	1.65	1.23	1.44	1.32	.66	1.72	.4	.06	4.0	.68	1.9	.31	.84	.88	1.00
			260	7.5	6.3	1.30	1.37	1.57	1.53	1.21	1.37	1.03	.67	1.00	.6	.09	4.5	.71	2.3	.36	.86	.88	1.00
			300	8.9	7.3	1.90	1.06	1.14	1.07	1.08	1.08	.90	.63	1.15	1.3	.18	6.1	.84	3.4	.47	.92	.93	.99
			340	8.0	6.4	1.80	.63	.73	.66	.61	.64	.37	.37	.73	1.1	.17	5.0	.77	2.9	.45	.86	.86	.99
Mean of 7 curves				7.5	6.0	1.59	1.24									.13		.74		.39	.86	.89	1.00
February 15 [a]	6.80	5.90	60	6.0	4.5	1.40	1.09	1.32	1.09	1.03	1.06	.57	.75	1.34	.9	.20	3.4	.75	1.9	.42	.81	.83	1.03
			140	7.6	5.3	2.20	1.60	1.92	1.45	1.75	1.60	.92	.65	1.97	1.4	.27	4.5	.84	3.2	.60	.81	.83	1.00
			180	7.3	6.1	1.20	1.58	1.80	1.80	1.34	1.57	1.25	.96	1.86	.6	.09	4.0	.66	2.2	.36	.85	.88	1.00
			220	7.2	5.8	1.30	1.44	1.63	1.66	1.19	1.42	1.38	.73	1.69	.2	.03	3.8	.66	1.9	.33	.85	.88	1.01
			260	7.5	6.2	1.30	1.36	1.48	1.48	1.27	1.38	1.04	.98	1.54	.8	.13	4.4	.70	2.1	.34	.88	.92	.98
			300	8.8	7.1	2.00	1.12	1.21	1.14	1.14	1.14	.90	.79	1.21	1.2	.17	5.8	.82	3.5	.49	.92	.93	.98
			340	8.0	6.3	1.70	.62	.70	.64	.59	.62	.44	.38	.71	1.0	.16	4.8	.76	2.5	.40	.87	.88	1.00
Mean of 7 curves				7.5	5.9	1.73	1.26									.15		.74		.42	.86	.88	1.00
February 17 [a]	6.56	5.61	60	5.6	4.1	1.60	1.09	1.27	1.07	1.07	1.07	.87	.70	1.29	1.0	.24	3.2	.78	2.4	.57	.85	.86	1.02
			140	7.2	5.0	2.20	1.49	1.81	1.32	1.53	1.42	.95	1.05	1.84	1.5	.29	4.1	.83	2.8	.56	.81	.82	1.04
			180	7.1	5.8	1.30	1.57	1.73	1.73	1.39	1.56	1.38	1.03	1.80	.5	.09	3.9	.68	1.9	.33	.87	.90	1.00
			220	7.0	5.6	1.40	1.29	1.55	1.62	.98	1.30	1.12	.45	1.70	.3	.05	3.7	.66	1.8	.32	.76	.84	1.00
			260	7.4	6.0	1.45	1.34	1.53	1.46	1.19	1.32	1.19	.77	1.54	.6	.10	4.2	.70	2.5	.42	.87	.88	1.01
			300	8.7	7.0	1.90	1.07	1.18	1.12	1.03	1.08	.85	.80	1.20	1.0	.14	5.2	.75	2.9	.41	.89	.91	1.00
			340	7.8	6.0	1.85	.55	.63	.59	.52	.56	.49	.14	.63	.7	.12	4.7	.78	3.0	.50	.88	.88	.99
Mean of 7 curves				7.3	5.6	1.67	1.20									.15		.74		.44	.85	.87	1.01

[a] Ice rough.

Vertical velocity measurements—Continued.

CONNECTICUT RIVER AT ORFORD, N. H.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 14 [a]	6.00	4.56	60	4.9	3.5	1.50	1.01	1.24	1.06	0.94	1.00	0.91	0.25	1.25	0.4	0.13	2.7	0.77	1.8	0.51	0.81	0.82	1.01
			140	6.6	4.5	2.15	1.38	1.60	1.45	1.24	1.34	1.12	.88	1.63	.7	.16	3.2	.71	1.8	.40	.84	.86	1.02
			180	6.2	4.9	1.40	1.39	1.56	1.58	1.22	1.40	1.05	.87	1.66	.5	.10	3.2	.66	1.6	.33	.84	.89	1.00
			220	6.5	5.2	1.35	1.18	1.34	1.43	.95	1.19	.99	.60	1.48	.4	.07	3.3	.63	1.4	.27	.80	.88	.99
			260	6.7	5.3	1.50	1.24	1.38	1.37	1.08	1.22	1.28	.72	1.41			3.5	.66	1.8	.35	.88	.90	1.01
			300	8.1	6.3	1.95	1.02	1.18	1.10	.95	1.02	.83	.49	1.20	.8	.14	4.7	.75	2.6	.41	.85	.87	1.00
			340	7.0	5.1	2.00	.56	.62	.60	.52	.56	.57	.31	.63			3.8	.73	2.5	.49	.89	.90	1.00
Mean of 7 curves				6.6	4.9	1.69	1.11									.09		.70		.39	.84	.88	1.00
March 15 [a]	5.59	4.15	60	4.6	3.2	1.50	1.01	1.20	1.17	.88	1.02	.90	.17	1.23	.2	.07	2.3	.72	1.2	.38	.82	.84	.99
			140	6.2	4.2	2.10	1.36	1.52	1.43	1.27	1.35	1.05	1.02	1.55	.6	.15	3.0	.72	1.6	.38	.88	.90	1.01
			180	6.0	4.6	1.50	1.36	1.50	1.45	1.23	1.34	1.33	.80	1.50	.2	.03	3.2	.71	1.8	.39	.90	.90	1.01
			220	6.1	4.7	1.45	1.12	1.27	1.35	.90	1.12	1.08	.55	1.38	.1	.02	3.0	.63	1.4	.31	.81	.88	1.00
			260	6.5	5.1	1.50	1.22	1.37	1.35	1.08	1.22	1.12	.77	1.40	.4	.07	3.5	.68	1.8	.35	.87	.89	1.00
			300	7.5	5.7	1.90	.98	1.10	1.05	.90	.98	.86	.55	1.13	.7	.12	4.1	.72	2.1	.37	.86	.89	1.00
			340	6.7	4.8	2.00	.51	.58	.55	.47	.51	.43	.30	.60	.6	.12	3.4	.71	1.8	.38	.85	.88	1.00
Mean of 7 curves				6.2	4.6	1.71	1.08									.08		.70		.37	.86	.88	1.00

DES MOINES RIVER AT KEOSAUQUA, IOWA.[b]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Max. velocity In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.																							
January 13 [a]	2.45	2.10	50	4.2	3.7	0.5	1.19	1.32	1.33	1.07	1.20	1.08	0.60	1.37	0.2	0.05	2.6	0.70	1.2	0.32	0.87	0.90	0.99
			350	5.5	5.0	.5	1.86	2.35	1.79	1.87	1.83	.63	.95	2.35	1.0	.21	4.0	.80	2.5	.50	.79	.79	1.02
			380	5.6	5.1	.5	1.82	2.03	1.98	1.66	1.82	1.25	1.30	2.09	.7	.14	3.5	.69	1.8	.35	.87	.90	1.00
			410	6.3	5.8	.5	1.65	1.87	1.91	1.39	1.65	1.35	.92	1.97	.5	.09	3.8	.66	1.8	.32	.84	.88	1.00
			520	4.5	4.2	.3	1.38	1.52	1.41	1.38	1.38	1.15	.78	1.52	.8	.18	3.4	.81	2.2	.51	.91	.91	1.00
Mean of 5 curves				5.2	4.8	.46	1.58									.13		.73		.40	.86	.88	1.00

[a] Ice rough.

[b] Gravel bed.

Vertical velocity measurements—Continued.

ESOPUS CREEK AT KINGSTON, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1901.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
December 4	5.28	......	90	6.8	6.7	0.10	0.91	1.10	0.88	0.88	0.88	0.60	0.20	1.10	1.4	0.21	5.1	0.76	3.7	0.55	0.83	0.83	1.03
			100	5.0	4.9	.10	.98	1.08	1.03	.93	.98	.88	.10	1.08	.5	.10	3.6	.73	2.4	.49	.91	.91	1.00
Mean of 2 curves	......	......	......	5.9	5.8	.10	.94	......	......	......	......	......	......	......	......	.16	......	.74	......	.52	.87	.87	1.02
1902.																							
January 9	6.54	......	70	4.2	......	(b)	1.28	1.50	1.43	1.13	1.28	1.05	.40	1.55	.4	.10	3.0	.71	1.5	.36	.83	.85	1.00
			80	6.8	6.6	.20	1.39	1.50	1.50	1.33	1.42	1.05	.90	1.53	.8	.11	4.8	.73	.8	.12	.91	.93	.98
			90	8.1	8.0	.10	1.15	1.33	1.38	.96	1.17	.90	.30	1.40	.4	.05	5.4	.68	2.3	.29	.82	.86	.98
			100	6.1	6.0	.10	1.20	1.32	1.28	1.18	1.23	.80	.50	1.32	1.0	.11	4.7	.78	2.4	.40	.91	.91	.98
Mean of 4 curves	......	......	......	6.3	5.2	.10	1.25	......	......	......	......	......	......	......	......	.09	......	.72	......	.29	.87	.89	.98
December 11	6.6	......	30	3.0	2.9	.10	.87	1.05	1.10	.82	.96	.25	.20	1.11	.2	.05	2.4	.82	.8	.26	.78	.83	.91
			40	4.0	3.9	.10	1.14	1.28	1.37	.93	1.15	.30	.55	1.40	.3	.08	2.7	.69	1.2	.31	.81	.89	.99
			50	3.2	3.1	.10	1.21	1.50	1.60	.83	1.22	.50	.00	1.65	.2	.06	2.0	.66	1.0	.32	.73	.80	.99
			60	3.8	3.7	.10	1.24	1.39	1.50	1.05	1.28	.50	.50	1.53	.3	.08	2.4	.65	1.1	.29	.81	.89	.97
			70	4.2	4.1	.10	1.28	1.42	1.55	.98	1.26	1.25	.60	1.55	......	......	2.6	.63	1.0	.24	.83	.90	1.02
			80	7.0	6.9	.10	1.27	1.48	1.53	1.13	1.33	.50	.00	1.55	.4	.06	5.1	.74	2.0	.29	.82	.86	.96
			90	8.0	7.9	.10	1.17	1.23	1.43	.91	1.17	1.00	.10	1.45	.2	.03	4.4	.56	2.1	.27	.80	.95	1.00
			100	6.2	6.1	.10	1.06	1.23	1.24	.91	1.08	.82	.30	1.28	.5	.08	4.1	.67	2.2	.36	.83	.86	.98
Mean of 8 curves	......	......	......	4.9	4.8	.10	1.16	......	......	......	......	......	......	......	......	.06	......	.68	......	.29	.80	.87	.98
1903.																							
January 14	6.90	......	55	3.5	2.9	.60	1.08	1.12	1.31	.97	1.14	.80	.40	1.32	.2	.07	1.7	.59	.8	.28	.82	.96	.95
			70	4.2	3.6	.60	1.08	1.22	1.30	.95	1.12	.96	.34	1.32	.2	.06	2.6	.72	1.0	.28	.82	.88	.96
			90	7.7	7.1	.60	1.01	1.09	1.19	.88	1.04	.94	.15	1.22	.2	.02	4.2	.59	2.0	.28	.83	.92	.97
			105	4.6	4.0	.60	.90	1.15	1.00	.70	.85	.65	.05	1.16	.4	.11	2.9	.73	2.2	.56	.78	.79	1.06
Mean of 4 curves	......	......	......	5.0	4.4	.60	1.02	......	......	......	......	......	......	......	......	06	......	.66	......	.35	.81	.89	.98

[a] Sand and gravel bed.

[b] Edge ice

Vertical velocity measurements—Continued.

ESOPUS CREEK AT KINGSTON, N. Y.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1903.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 24	7.10		60	4.2	3.8	0.40	1.40	1.75	1.82	1.00	1.46	1.00	0.35	1.90	0.3	0.07	2.5	0.66	1.3	0.34	0.74	0.80	0.96
			70	4.8	4.4	.40	1.54	1.80	1.88	1.28	1.58	1.12	.60	1.96	.3	.07	3.1	.71	1.5	.34	.79	.85	.97
			85	7.2	6.8	.40	1.60	1.78	1.70	1.42	1.56	1.40	1.00	1.82	.8	.12	4.4	.65	2.8	.41	.88	.90	1.03
			90	7.8	7.4	.40	1.50	1.80	1.63	1.38	1.50	1.22	.60	1.73	.9	.12	5.3	.72	3.0	.40	.87	.83	1.00
Mean of 4 curves				6.0	5.6	.40	1.51									.09		.68		.37	.82	.84	.99
1906.																							
February 15	5.60		30	2.4	1.8	.70	.45	.47	.56	.31	.44	.52	.18	.56			1.0	.53	.3	.17	.80	.96	1.03
			40	2.7	2.2	.62	.83	.93	.96	.75	.86	.70	.58	1.00	.2	.10	1.4	.64	.6	.28	.83	.90	.98
			60	2.9	2.5	.50	.73	.82	1.21	.16	.68	.92	.00	1.22			1.4	.55	.5	.20	.20	.89	1.07
			110	2.5	2.0	.60	.50	.78	.78	.22	.50	.55	.00	.82			1.2	.60	.3	.13	.61	.64	1.00
Mean of 4 curves				2.6	2.1	.60	.62									.02		.58		.19	.71	.84	1.02
February 15	5.60		70	3.9	3.5	.50	.99	1.24	1.30	.68	.99	1.08	.30	1.30			2.2	.62	.8	.23	.76	.80	1.00
			80	5.6	5.2	.48	1.09	1.22	1.15	1.03	1.09	.75	.55	1.22	.5	.10	3.9	.75	2.3	.44	.90	.90	1.00
			90	5.2	4.8	.52	.96	1.10	1.18	.75	.96	.86	.35	1.20	1.2	.02	3.1	.64	1.3	.26	.80	.87	.99
			100	5.6	5.1	.58	.88	1.02	1.10	.67	.88	.40	.25	1.14	.3	.06	3.5	.69	1.5	.29	.85	.86	1.00
Mean of 4 curves				5.1	4.6	.52	.98									.04		.68		.30	.82	.86	1.00

FISH RIVER AT WALLAGRASS, ME.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Max. In feet.	Max. In per cent of depth.	Coef. Maximum.	Coef. 0.5 depth.	Coef. $\frac{0.2+0.8}{2}$ depth.
1906.																							
February 15	3.91	3.25	90	3.2	1.7	1.5	0.84	0.98	0.93	0.72	0.82	0.83	0.49	0.97	0.0	0.02	1.2	0.69	0.6	0.35	0.87	0.86	1.02
			110	4.5	3.3	1.2	1.17	1.30	1.20	1.11	1.16	.98	.84	1.30	.5	.15	2.4	.74	1.6	.50	.90	.90	1.01
			130	4.8	3.6	1.2	1.04	1.19	1.20	.89	1.04	.87	.44	1.25	.2	.07	2.4	.68	1.0	.29	.83	.87	1.00
			150	3.0	1.3	1.7	.52	.56	.56	.49	.52	.50	.12	.57	1	.05	1.0	.73	.4	.27	.91	.93	.99
Mean of 4 curves				3.9	2.5	1.40	.89									.07		.71		.35	.88	.89	1.01

[a] Gravel bed.

Vertical velocity measurements—Continued.

FISH RIVER AT WALLAGRASS, ME.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 15	3.91	3.25	90	3.2	1.7	1.5	0.87	0.98	0.93	0.77	0.85	0.83	0.62	0.97	0.1	0.06	1.2	0.68	0.6	0.35	0.90	0.89	1.02
			110	4.5	3.3	1.2	1.18	1.30	1.24	1.13	1.18	1.03	.76	1.30	.4	.12	2.5	.76	1.6	.50	.91	.91	1.00
			130	4.8	3.6	1.2	1.03	1.17	1.17	.93	1.05	.76	.50	1.20	.4	.10	2.6	.72	1.3	.36	.86	.88	.98
			150	3.0	1.3	1.7	.55	.58	.60	.49	.54	.57	.42	.60	.0	.00	.8	.62	.3	.23	.91	.95	1.00
Mean of 4 curves	......	......	......	3.9	2.5	1.40	.91	......	......	......	......	......	......	......	......	.07	......	.70	......	.36	.89	.90	1.00
March 15	4.99	3.83	90	4.3	2.9	1.4	1.22	1.45	1.28	1.15	1.22	.70	.74	1.45	.5	.16	2.2	.76	1.3	.45	.84	.84	1.01
			110	5.6	4.3	1.3	1.50	1.74	1.42	1.62	1.52	.73	1.06	1.79	1.0	.24	3.6	.85	2.7	.63	.84	.86	.98
			130	5.9	4.6	1.3	1.39	1.70	1.53	1.43	1.48	.43	.35	1.71	.8	.16	3.8	.82	1.9	.41	.81	.82	.94
			150	4.1	2.3	1.8	.88	.95	1.01	.78	.90	.90	.45	1.01	......	......	1.5	.64	.5	.22	.87	.92	.98
Mean of 4 curves	......	......	......	5.0	3.5	1.45	1.25	......	......	......	......	......	......	......	......	.14	......	.77	......	.43	.84	.86	.98
March 15	5.08	3.92	90	4.4	3.0	1.4	1.24	1.44	1.33	1.17	1.25	.70	.80	1.45	.5	.16	2.2	.75	1.4	.47	.86	.86	.99
			110	5.6	4.3	1.3	1.52	1.76	1.46	1.62	1.54	.77	1.07	1.79	1.0	.22	3.6	.85	2.7	.63	.85	.86	.99
			130	6.0	4.7	1.3	1.40	1.70	1.56	1.42	1.49	.44	.34	1.72	.7	.15	3.8	.81	1.8	.38	.81	.82	.94
			150	4.3	2.5	1.8	.87	.95	1.04	.74	.89	.92	.35	1.04	......	......	1.6	.66	.6	.24	.84	.92	.98
Mean of 4 curves	......	......	......	5.1	3.6	1.45	1.26	......	......	......	......	......	......	......	......	.13	......	.77	......	.43	.84	.87	.97

FLAMBEAU RIVER AT LADYSMITH, WIS.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Max. thread In feet.	In per cent of depth.	Coef. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.																							
January 26	16.13	15.33	120	4.0	3.1	0.9	1.68	1.77	1.90	1.44	1.67	1.88	1.05	1.90	......	......	1.9	0.61	0.4	0.13	0.88	0.95	1.00
			140	3.3	2.3	1.0	1.62	1.71	1.79	1.46	1.62	1.78	1.12	1.79	......	......	1.5	.65	.3	.13	.90	.95	1.00
Mean of 2 curves	......	......	......	3.6	2.7	.95	1.65	......	......	......	......	......	......	......	......	......	......	.63	......	.13	.89	.95	1.00

[a] Coarse gravel bed.

Vertical velocity measurements—Continued.

GENESEE RIVER AT MOUNT MORRIS (JONES BRIDGE), N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves: Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity: Upper, In feet.	Upper, In per cent of depth.	Lower, In feet.	Lower, In per cent of depth.	Depth of thread of maximum velocity: In feet.	In per cent of depth.	Coefficients for reducing to mean velocity: Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 12	5.75	......	110	4.9	4.4	0.50	2.23	3.02	2.31	2.04	2.18	0.63	1.06	3.08	0.8	0.18	3.3	0.75	2.0	0.44	0.72	0.74	1.02
			120	5.7	4.7	.40	1.66	2.34	1.08	2.04	1.56	.00	.96	2.48	1.4	.31	4.1	.87	2.8	.60	.67	.71	1.06
			130	5.3	4.9	.40	2.28	2.56	2.87	1.68	2.28	2.48	1.07	2.92	.0	......	3.0	.61	1.3	.26	.78	.89	1.00
			140	4.2	3.8	.40	1.20	1.41	1.47	.93	1.20	1.24	.62	1.48	.0	......	2.6	.67	1.1	.29	.82	.86	1.06
February 13	5.78	......	110	5.1	4.6	.45	1.63	2.07	2.12	1.23	1.68	1.13	.10	2.26	.35	.08	3.2	.68	1.4	.30	.72	.79	.98
			115	5.0	4.5	.50	2.47	3.00	2.79	2.16	2.48	.34	1.61	3.27	.65	.14	3.1	.69	1.6	.36	.76	.82	1.00
			130	5.5	5.2	.30	2.06	2.29	2.74	1.42	2.08	2.57	.63	2.74	......	......	3.0	.59	1.2	.22	.75	.90	.99
			135	5.5	5.2	.30	1.70	2.01	2.07	1.25	1.66	1.86	.58	2.16	......	......	3.3	.64	2.0	.38	.79	.85	1.03
			140	4.5	4.2	.35	.88	1.22	1.10	.57	.84	.94	.00	1.23	......	......	2.9	.70	1.9	.46	.72	.72	1.05
February 16	6.00	......	17	3.3	2.8	.55	.64	.68	.64	.62	.63	.55	.56	.68	.6	.21	2.0	.71	1.2	.43	.93	.94	1.01
			27	3.0	2.4	.60	1.15	1.38	1.34	.99	1.16	.85	.72	1.45	.2	.10	1.7	.69	.9	.37	.79	.83	.99
			37	3.1	2.6	.60	1.63	1.83	1.79	1.41	1.60	1.49	.98	1.88	.2	.08	1.7	.68	1.0	.37	.87	.89	1.02
			47	3.5	3.0	.60	1.92	2.22	2.18	1.71	1.94	1.56	1.20	2.34	.3	.09	2.1	.70	.9	.32	.82	.87	.99
			57	3.5	2.9	.60	1.99	2.19	2.34	1.66	2.00	1.90	1.22	2.34	.05	.02	1.9	.66	.6	.19	.85	.91	1.00
			67	3.6	3.0	.60	2.06	2.30	2.34	1.79	2.06	1.89	1.40	2.37	.2	.05	2.0	.66	.9	.30	.87	.89	1.00
			77	4.4	3.8	.60	1.95	2.13	2.28	1.61	1.94	1.93	1.28	2.32	.0	......	2.4	.61	1.2	.31	.84	.92	1.00
			87	4.9	4.4	.60	1.84	2.14	2.02	1.55	1.78	1.50	1.11	2.17	.4	.10	2.8	.64	1.8	.40	.85	.86	1.03
			97	4.7	4.2	.80	1.46	1.65	1.71	1.20	1.46	.87	.90	1.78	.2	.06	2.6	.62	1.8	.45	.82	.89	1.01
			107	4.0	3.4	.80	1.04	1.11	1.20	.93	1.06	.78	.78	1.21	.2	.04	2.1	.61	.7	.20	.86	.93	.97
			117	2.8	2.2	.80	.59	.72	.76	.47	.62	.74	.03	.76	......	......	1.6	.70	.6	.18	.78	.82	.96
Mean of 20 curves	......	......	......	8.6	3.8	.54	1.62	......	......	......	......	......	......	......	......	.07	......	.67	......	.34	.80	.85	1.01
February 12[b]	5.75	......	90	3.8	2.4	.60	.98	1.54	1.22	1.46	1.34	.0	1.21	1.56	.2	.06	......	......	1.3	.54	.63	.64	.73
			100	4.9	3.6	.45	1.98	3.20	2.10	2.64	1.42	.0	1.76	3.23	.6	.02	3.5	.97	2.0	.56	.61	.62	1.39
February 13[b]	5.78	......	90	3.9	2.8	.60	1.14	1.66	1.14	1.48	.98	.0	1.08	1.67	.6	.19	2.8	.98	1.6	.56	.68	.69	.86
			95	4.1	3.2	.30	1.62	2.26	1.26	2.45	1.44	.0	2.26	2.46	1.8	.57	......	......	2.2	.69	.66	.72	1.12
			100	4.6	4.2	.40	2.36	3.25	1.56	2.95	2.26	.0	1.89	3.36	1.3	.31	3.9	.93	2.5	.60	.70	.73	1.04
			105	5.4	5.0	.40	2.18	3.23	1.32	2.58	1.95	.16	1.62	3.25	1.7	.34	4.4	.88	2.6	.51	.67	.68	1.12
			125	5.1	4.2	.30	2.35	3.06	2.94	2.49	2.60	.0	1.66	3.06	.2	.04	3.5	.83	1.8	.43	.77	.77	.90
Mean of 7 curves	......	......	......	4.5	3.6	.44	1.80	......	......	......	......	......	......	......	......	.22	......	.66	......	.56	.68	.69	1.02

[a] Coarse gravel bed.

[b] Needle ice.

Vertical velocity measurements—Continued.

GENESEE RIVER AT ELMWOOD AVENUE BRIDGE, ROCHESTER, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.																	
February 15	1.55	......	40	4.2	3.9	0.3	0.92	1.04	1.08	0.76	0.92	1.05	0.26	1.10	......	......	2.7	0.69	1.2	0.31	0.84	0.89	1.00
			50	4.3	4.0	.3	.89	1.04	1.08	.72	.90	1.05	.10	1.10	......	......	2.8	.70	1.2	.30	.81	.86	.99
			60	4.5	4.2	.3	1.06	1.18	1.18	.98	1.08	1.12	.48	1.20	......	......	3.1	.74	1.5	.36	.89	.90	.99
			70	5.1	4.8	.3	.92	1.17	1.20	.60	.90	1.10	.00	1.23	......	......	3.4	.71	1.6	.33	.75	.78	1.02
			80	3.7	3.4	.3	1.24	1.35	1.28	1.18	1.23	1.04	.95	1.35	0.5	0.02	2.6	.76	1.5	.44	.91	.92	1.01
			90	3.8	3.5	.3	1.00	1.30	1.33	.66	1.00	1.24	.00	1.36	......	......	2.4	.68	1.4	.40	.74	.77	1.01
			100	3.5	3.0	.45	1.23	1.40	1.36	1.04	1.20	1.25	.65	1.40	......	......	2.2	.72	1.4	.46	.88	.88	1.03
			110	4.3	3.8	.5	1.20	1.34	1.36	1.03	1.20	1.15	.70	1.40	......	......	2.6	.68	1.2	.32	.86	.90	1.01
			120	4.2	3.7	.5	.93	1.05	1.24	.65	.94	1.20	.20	1.24	......	......	2.3	.62	.6	.16	.75	.89	.99
			140	3.0	2.5	.5	.83	1.00	1.10	.55	.82	1.04	.10	1.10	......	......	1.6	.64	.6	.24	.75	.83	1.00
			150	4.6	4.1	.5	.88	1.14	1.08	.72	.90	.86	.00	1.15	......	......	3.0	.74	1.8	.44	.76	.77	.98
			160	4.3	3.8	.5	.69	.76	.78	.66	.72	.68	.40	.80	......	......	3.0	.79	1.0	.26	.86	.91	.96
			170	4.5	4.0	.5	.82	.86	.88	.75	.82	.74	.66	.90	.1	.02	3.0	.74	1.2	.30	.91	.95	1.00
			180	5.0	4.5	.5	.76	.80	.80	.64	.72	.82	.25	.80	......	......	3.0	.67	1.9	.42	.95	.95	1.05
			190	5.0	4.5	.5	.73	.76	.90	.52	.71	.75	.33	.90	......	......	2.5	.56	.8	.18	.82	.97	1.03
			200	4.1	4.6	.5	.86	.92	.85	.81	.83	.60	.66	.92	.7	.02	2.7	.58	1.6	.35	.93	.93	1.04
			210	4.3	3.8	.5	.70	.80	.86	.63	.74	.74	.30	.86	......	......	2.7	.71	.8	.21	.82	.88	.94
			220	4.3	3.8	.5	.68	.82	.82	.58	.70	.68	.35	.85	......	......	2.7	.72	1.2	.30	.80	.83	.98
			250	3.3	2.9	.5	.50	.74	.50	.46	.48	.12	.10	.74	.6	.21	2.2	.77	1.5	.51	.68	.68	1.05
Mean of 19 curves	......	......	......	4.4	3.8	.43	.89	......	......	......	......	......	......	......	......	.01	......	.70	......	.33	.82	.87	1.00

[a] Coarse gravel bed.

Vertical velocity measurements—Continued.

GENESEE RIVER ONE-FOURTH MILE ABOVE ELMWOOD AVENUE BRIDGE, ROCHESTER, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 14	1.42	......	40	7.9	7.4	0.50	0.40	0.46	0.45	0.36	0.40	0.34	0.22	0.50	0.8	0.11	5.0	0.68	3.1	0.42	0.81	0.88	1.00
			60	8.0	7.5	.50	.43	.52	.50	.46	.48	.36	.06	.52	.4	.05	5.5	.73	3.1	.41	.83	.83	.90
			80	7.1	6.6	.45	.46	.52	.56	.34	.45	.28	.16	.58	.4	.07	4.2	.63	1.7	.26	.79	.88	1.01
			100	7.7	7.3	.40	.42	.45	.44	.42	.43	.40	.24	.45	.6	.08	5.9	.81	4.8	.66	.94	.94	.99
			120	7.7	7.3	.40	.52	.58	.54	.50	.52	.32	.38	.58	1.0	.14	5.8	.79	3.3	.45	.89	.89	1.00
			140	8.1	7.7	.40	.46	.50	.44	.45	.44	.23	.32	.51	1.5	.19	6.4	.83	4.3	.56	.91	.92	1.04
			160	7.4	7.0	.40	.49	.58	.50	.48	.49	.25	.18	.58	1.0	.14	5.7	.81	3.6	.51	.84	.84	.99
			180	7.1	6.7	.40	.46	.56	.53	.47	.50	.36	.00	.56	.5	.08	5.4	.81	3.1	.46	.83	.83	.93
			200	6.4	5.9	.50	.42	.52	.55	.26	.40	.48	.00	.55	.0	.00	4.0	.68	1.5	.25	.77	.81	1.04
			220	5.4	4.9	.50	.48	.55	.48	.48	.48	.30	.25	.55	.9	.08	4.0	.41	3.0	.31	.87	.87	1.00
			240	5.2	4.7	.50	.40	.50	.45	.38	.42	.36	.00	.50	.4	.08	3.7	.79	2.5	.53	.81	.81	.98
Mean of 11 curves	......	......	......	7.1	6.6	.45	.45	......	......	......	......	......	......	......	......	.09	......	.72	......	.44	.84	.86	.99

HOOSIC RIVER AT BUSKIRK, N. Y.[b]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Max. In feet.	Max. In per cent of depth.	Coef. Maximum.	Coef. 0.5 depth.	Coef. $\frac{0.2+0.8}{2}$ depth.
1906.																							
February 10[c]	3.90	......	60	4.6	4.2	0.35	0.90	1.38	1.03	1.40	1.21	0.0	1.35	1.40	0.4	0.11	0.0	......	2.0	0.47	0.61	0.65	0.75
			70	5.5	5.1	.40	1.80	2.06	1.58	2.15	1.86	.0	2.15	2.15	1.2	.23	......	......	4.0	.78	.84	.88	.97
			80	6.9	6.4	.45	1.81	2.52	2.15	2.30	2.22	.0	1.95	2.53	.8	.12	......	......	2.7	.42	.72	.72	.81
			90	8.1	7.6	.45	1.54	2.75	2.25	2.10	2.18	.0	1.10	2.75	.6	.08	5.2	0.68	2.9	.38	.56	.56	.71
			100	7.5	7.0	.45	1.64	2.68	1.35	2.30	1.82	.0	1.00	2.80	1.6	.22	5.6	.79	3.7	.52	.59	.61	.90
			110	6.6	6.2	.45	.81	2.16	2.06	1.68	1.87	.0	1.12	2.23	.0	......	......	......	1.0	.16	.56	.38	.43
Mean of 6 curves	......	......	......	6.6	6.1	.38	1.57	......	......	......	......	......	......	......	......	.13	......	.24	......	.45	.62	.63	.76

[a] Coarse gravel bed.

[b] Gravel bed.

[c] More or less needle ice under ice surface on all of these curves.

Vertical velocity measurements—Continued.

KENNEBEC RIVER AT NORTH ANSON, ME.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1904.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 2	3.55	±1.45	50		0.9	1.9	1.78	1.97	1.95	1.56	1.75	1.80	1.16	2.00	0.0	0.00	0.6	0.67	0.4	0.44	0.89	0.90	1.02
			60		1.1	1.8	1.84	2.09	1.78	1.89	1.83	1.32	1.40	2.10	.2	.18	.9	.82	.6	.55	.88	.88	1.00
			70		1.1	2.0	1.66	1.89	1.84	1.43	1.63	1.60	1.00	1.92	.1	.09	.7	.63	.4	.36	.86	.88	1.02
			80		1.6	1.9	1.77	2.24	1.65	1.78	1.72	1.08	1.08	2.24	.4	.25	1.3	.81	.8	.50	.79	.79	.98
			90		1.9	2.0	2.26	2.76	2.30	2.20	2.25	1.76	1.30	2.77	.4	.21	1.5	.79	.9	.47	.81	.82	1.00
			100		2.2	2.0	2.29	2.76	2.60	1.98	2.29	1.80	.98	2.84	.2	.09	1.6	.73	.8	.36	.81	.83	1.00
			110		2.3	2.1	2.44	2.93	2.60	2.30	2.45	1.36	1.65	2.98	.4	.17	1.7	.74	1.0	.43	.82	.83	1.00
			120		2.2	2.4	2.25	3.10	2.18	2.42	2.30	.20	1.04	3.10	.5	.23	1.8	.82	1.1	.50	.73	.74	.98
			130		2.0	2.4	2.11	2.62	2.20	2.06	2.13	.82	1.32	2.66	.4	.20	1.6	.80	.8	.40	.79	.81	.99
			140		1.8	2.2	2.06	2.64	2.11	1.91	2.01	.92	1.26	2.72	.4	.22	1.3	.72	.7	.39	.76	.78	1.02
			150		1.7	2.3	1.92	2.45	2.10	1.85	1.97	1.14	.70	2.46	.3	.18	1.3	.77	.8	.47	.78	.80	.98
			160		1.4	2.3	1.75	2.16	1.70	1.72	1.71	.88	1.30	2.20	.3	.21	1.1	.79	.6	.43	.80	.82	1.02
			170		1.5	2.1	1.62	1.98	1.55	1.63	1.59	.80	1.20	2.00	.3	.20	1.2	.80	.6	.40	.81	.71	1.02
			180		1.1	2.4	1.25	1.60	1.12	1.30	1.21	.56	.84	1.62	.3	.27	.9	.82	.6	.55	.77	.78	1.04
			190		.9	2.4	1.13	1.30	1.11	1.09	1.10	.90	.84	1.30	.2	.22	.7	.78	.4	.44	.87	.87	1.02
Mean of 15 curves					1.6	2.15	1.87									.18		.77		.45	.81	.82	1.01
January 27	3.40	1.55	100		2.5		2.18	2.38	2.59	1.72	2.15	2.40	1.00	2.60			1.5	.60	.7	.28	.84	.91	1.02
			110		2.7		2.22	2.38	2.70	1.75	2.22	2.69	1.03	2.72			2.0	.74	.3	.11	.82	.93	1.00
			120		3.0		2.30	2.47	2.94	1.67	2.30	2.75	.86	2.94			1.7	.57	.6	.20	.78	.93	1.00
			130		2.7		2.38	2.60	2.92	1.82	2.37	2.83	.95	2.93			1.6	.59	.4	.15	.81	.92	1.00
Mean of 4 curves					2.7		2.27											.63		.19	.82	.92	1.00
1905. February 9	5.27	3.27	10½	3.2	1.3	1.9	1.06	1.16	1.06	1.06	1.06	.62	.85	1.17	.2	.15	1.06	.77	.6	.46	.91	.92	1.00
			31	3.8	1.8	2.0	1.36	1.60	1.62	1.04	1.33	1.22	.57	1.67	.1	.05	1.2	.67	.5	.28	.81	.85	1.02
			50	4.1	2.1	2.0	1.92	2.08	2.23	1.63	1.93	1.65	1.25	2.27	.0	.00	1.3	.62	.6	.29	.85	.93	1.00
			71½	5.2	3.2	2.1	2.00	2.27	2.37	1.63	2.00	1.45	.92	2.41	.1	.03	2.1	.66	1.0	.31	.83	.88	1.00
			92	6.1	4.2	2.0	2.23	2.54	2.44	1.96	2.20	1.60	1.45	2.63	.5	.12	2.8	.67	1.5	.36	.85	.88	1.01

[a] Gravel bed.

Vertical velocity measurements—Continued.

KENNEBEC RIVER AT NORTH ANSON, ME.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1905.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 9	5.27	3.27	112	6.1	4.2	1.9	2.36	2.74	2.62	2.08	2.35	1.60	1.40	2.80	0.5	0.12	2.9	0.69	1.5	0.36	0.84	0.86	1.00
			134	6.1	4.2	1.9	2.47	2.77	2.59	2.29	2.44	2.02	1.40	2.78	.5	.12	3.2	.76	2.1	.50	.89	.89	1.01
			154	6.0	4.0	2.0	2.32	2.57	2.58	2.10	2.34	1.00	1.72	2.69	.4	.10	2.7	.68	1.3	.32	.86	.90	.99
			173	6.0	4.0	2.0	2.18	2.50	2.34	2.00	2.17	.57	1.34	2.52	.5	.13	2.9	.72	1.8	.45	.86	.88	1.00
			194	6.0	3.9	2.0	1.57	1.98	1.44	1.74	1.58	.45	.60	1.98	.9	.23	3.3	.85	2.2	.56	.79	.79	.99
			216	6.3	4.1	2.2	.89	1.04	.86	.87	.88	.62	.45	1.04	1.2	.30	3.0	.73	2.3	.56	.86	.86	1.01
Mean of 11 curves				5.4	3.4	2.00	1.85									.12		.71		.40	.85	.88	1.00
February 9	5.32	3.32	10½	3.2	1.3	1.9	1.25	1.48	1.34	1.07	1.20	.00	.61	1.50	.2	.15	1.0	.77	.6	.46	.83	.85	1.04
			31	3.9	1.9	2.0	1.50	1.62	1.67	1.31	1.48	1.35	1.08	1.72	.1	.05	1.2	.63	.6	.31	.87	.93	1.01
			71½	5.2	3.2	2.1	2.02	2.44	2.36	1.58	1.97	1.82	.62	2.49	.1	.03	2.1	.66	1.3	.41	.81	.83	1.03
			112	6.2	4.2	1.9	2.42	2.72	2.74	2.07	2.41	1.95	1.35	2.80	.2	.05	2.9	.69	1.5	.36	.86	.89	1.00
			154	6.0	4.0	2.0	2.33	2.52	2.58	2.10	2.34	2.03	1.60	2.65	.3	.08	2.6	.65	1.2	.30	.88	.93	1.00
			194	6.1	3.9	2.0	1.63	1.87	1.64	1.61	1.62	1.08	1.00	1.88	.7	.18	3.0	.77	2.2	.56	.87	.87	1.00
			236	7.0	4.7	2.1	1.37	1.58	1.32	1.38	1.34	.94	.85	1.60	1.2	.25	3.8	.81	2.7	.57	.86	.87	1.02
			279	5.5	3.3	2.0	1.15	1.48	.72	1.52	1.12	.10	1.03	1.63	1.2	.36	3.1	.94	2.1	.64	.71	.78	1.03
			320	4.4	2.3	2.1	.70	.85	.78	.58	.68	.61	.14	.86	.1	.04	1.6	.70	1.0	.44	.81	.83	1.03
			361	3.7	1.6	2.1	.99	1.15	1.28	.67	.98	1.20	.10	1.30			1.0	.63	.4	.25	.76	.86	1.01
			409	4.5	2.6	1.9	.66	.90	.57	.67	.62	.25	.00	.96	.1	.04	1.3	.50	1.6	.62	.69	.74	1.06
			448	4.5	2.5	2.0	.41	.48	.43	.35	.39	.30	.20	.51	.6	.24	1.5	.60	1.0	.40	.80	.85	1.05
Mean of 12 curves				5.0	3.0	2.01	1.37									.12		.70		.44	.81	.85	1.02
1906.																							
January 10	3.40	2.05	90	4.0	2.8	1.3	1.40	1.53	1.58	1.18	1.38	1.35	.85	1.60	.1	.04	1.8	.65	.8	.29	.87	.91	1.01
			130	5.0	3.7	1.4	1.55	1.69	1.73	1.34	1.54	1.42	.95	1.75	.2	.04	2.5	.68	1.0	.28	.88	.92	1.01
			290	4.4	3.2	1.3	1.45	1.55	1.62	1.29	1.46	1.42	.97	1.62	.1	.02	2.1	.66	.8	.26	.90	.94	1.00
			330	3.1	2.1	1.1	1.23	1.31	1.37	1.07	1.22	1.27	.81	1.37			1.3	.64	.5	.23	.90	.94	1.01
			370	2.6	1.5	1.3	.74	.88	.93	.52	.72	.78	.19	.95			1.0	.65	.4	.30	.78	.84	1.02
			410	2.9	1.8	1.3	.58	.68	.66	.46	.56	.53	.25	.71	.1	.07	1.2	.67	.7	.38	.82	.85	1.04
Mean of 6 curves				3.7	2.5	1.28	1.16									.03		.66		.29	.86	.90	1.02

Vertical velocity measurements—Continued.

KENNEBEC RIVER AT NORTH ANSON, ME.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
January 10	3.56	2.21	90	4.2	3.1	1.2	1.35	1.52	1.51	1.13	1.32	1.24	0.77	1.59	0.2	0.06	2.1	0.68	1.0	0.32	0.85	0.89	1.02
			130	5.1	3.7	1.5	1.65	1.74	1.78	1.50	1.64	1.50	1.25	1.82	.2	.07	2.3	.63	1.2	.32	.91	.95	1.01
			290	4.6	3.4	1.3	1.45	1.59	1.60	1.29	1.44	1.32	.93	1.64	.3	.08	2.3	.68	1.1	.32	.89	.92	1.01
			330	3.3	2.2	1.2	1.21	1.31	1.36	1.03	1.20	1.22	.71	1.37			1.4	.65	.6	.26	.88	.92	1.01
			370	2.7	1.6	1.3	.78	.87	.85	.65	.75	.73	.51	.90	.1	.08	1.0	.64	.6	.38	.86	.89	1.04
			410	3.1	1.9	1.4	.64	.70	.75	.52	.64	.64	.36	.77	.0	.00	1.2	.61	.5	.26	.84	.92	1.02
Mean of 6 curves				3.8	2.6	1.32	1.18									.05		.65		.31	.87	.92	1.02
March 2	4.26	2.43	70	3.3	1.8	1.6	1.48	1.72	1.62	1.34	1.48	1.33	.40	1.72	.2	.09	1.3	.73	.8	.47	.86	.86	1.00
			90	4.9	3.3	1.7	1.67	1.85	1.84	1.56	1.70	1.42	.75	1.92	.3	.09	2.4	.73	1.1	.33	.87	.90	.98
			130	5.9	3.9	2.0	1.94	2.15	2.18	1.70	1.94	1.97	1.14	2.20			2.6	.67	1.3	.33	.88	.90	1.00
			170	5.5	3.7	1.9	1.71	1.92	1.97	1.52	1.74	1.39	.94	2.00	.3	.08	2.6	.69	1.1	.30	.86	.89	.98
			210	4.7	3.0	1.9	1.15	1.30	1.34	1.01	1.18	.75	.66	1.38	.3	.09	2.0	.68	.9	.30	.83	.88	.98
			290	5.3	3.4	2.0	1.58	1.73	1.77	1.43	1.60	1.27	1.10	1.79	.3	.08	2.3	.68	1.0	.28	.88	.91	.98
			330	4.1	2.3	1.9	1.40	1.53	1.58	1.23	1.40	1.15	.92	1.61	.2	.07	1.5	.66	.7	.30	.87	.91	.99
			370	3.5	1.7	2.0	1.05	1.19	1.21	.87	1.04	1.00	.52	1.27	.1	.04	1.1	.66	.6	.32	.82	.88	1.00
			410	3.8	1.9	2.0	.90	1.00	1.07	.73	.90	.93	.50	1.07			1.2	.63	.5	.26	.84	.90	1.00
			450	3.3	1.5	2.0	.68	.74	.73	.65	.69	.68	.30	.74	.0	.00	1.1	.75	.6	.40	.92	.92	.99
Mean of 10 curves				4.4	2.6	1.90	1.35									.05		.69		.33	.86	.90	.99
March 3	4.08	2.27	70	3.1	1.6	1.7	1.38	1.55	1.50	1.23	1.36	1.14	.97	1.63	.2	.12	1.1	.68	.6	.37	.84	.89	1.01
			130	5.7	3.7	2.0	1.86	1.99	2.09	1.63	1.86	1.78	1.30	2.10	.1	.03	2.3	.63	1.0	.27	.88	.93	1.00
			170	5.3	3.5	2.0	1.68	1.83	1.89	1.54	1.72	1.48	.90	1.90	.2	.05	2.5	.71	.9	.26	.88	.92	.98
			210	4.5	2.8	1.9	1.06	1.23	1.23	.92	1.08	.86	.48	1.28	.2	.07	2.0	.70	.9	.32	.83	.86	.99
			290	5.0	3.1	2.0	1.43	1.57	1.64	1.28	1.46	.95	.95	1.66	.2	.08	2.1	.67	.9	.29	.86	.91	.98
			330	3.8	2.1	1.8	1.31	1.42	1.38	1.23	1.30	1.14	1.00	1.44	.3	.13	1.5	.70	.8	.38	.91	.92	1.00
			370	3.2	1.4	2.0	.97	1.10	1.06	.86	.96	.92	.43	1.12	.1	.06	1.0	.71	.6	.39	.86	.88	1.01
			410	3.6	1.8	2.0	.78	.88	.86	.69	.78	.75	.40	.90	.1	.07	1.2	.68	.7	.39	.87	.89	1.01
			450	3.1	1.4	1.9	.61	.67	.62	.59	.60	.52	.48	.67	.3	.20	1.1	.76	.8	.54	.91	.91	1.00
Mean of 9 curves				4.2	2.4	1.92	1.23									.09		.69		.36	.87	.90	1.00

Vertical velocity measurements—Continued.

KENNEBEC RIVER AT NORTH ANSON, ME.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 30	4.77	......	90	5.5	3.5	2.2	1.53	1.78	1.72	1.36	1.54	1.18	0.80	1.82	0.4	0.12	2.5	0.72	1.3	0.37	0.84	0.86	1.00
			130	6.3	4.1	2.3	2.00	2.23	2.25	1.76	2.00	1.67	1.26	2.29	.3	.07	2.8	.68	1.5	.36	.88	.90	1.00
			170	6.0	3.9	2.3	1.74	1.99	1.98	1.50	1.74	1.55	.88	2.06	.3	.08	2.7	.69	1.4	.36	.84	.87	1.00
			210	5.1	3.0	2,3	1.21	1.36	1.39	1.12	1.26	.69	.85	1.42	.3	.11	2.1	.70	.8	.28	.85	.89	.96
			290	5.7	3.4	2.5	1.52	1.63	1.72	1.39	1.56	1.15	1.12	1.72	.3	.08	2.2	.66	.8	.24	.88	.93	.98
			330	4.6	2.4	2.3	1.39	1.49	1.47	1.30	1.38	1.40	.89	1.50	......	......	1.7	.71	.9	.38	.93	.93	1.00
			370	4.0	1.8	2.4	1.04	1.19	1.23	.96	1.10	.59	.53	1.25	.2	.10	1.3	.72	.4	.25	.84	.88	.95
			410	4.1	1.9	2.4	.93	1.02	1.03	.84	.94	.89	.60	1.04	.1	.05	1.3	.68	.6	.34	.90	.91	1.00
			450	4.0	1.8	2.4	.61	.70	.69	.56	.62	.48	.36	.73	.2	.09	1.3	.72	.6	.30	.84	.87	.98
Mean of 9 curves	......	......	......	5.0	2.9	2.34	1.33	......	......	......	......	......	......	......	......	.08	......	.70	......	.32	.87	.90	.98
April 11	4.70	2.80	90	5.4	3.6	1.8	1.50	1.81	1.50	1.50	1.50	.75	.90	1.82	.7	.20	2.9	.80	1.7	.47	.83	.83	1.00
			130	6.3	4.3	2.0	1.90	2.14	2.00	1.84	1.92	1.30	1.22	2.16	.6	.15	3.4	.80	1.7	.40	.88	.89	.99
			170	5.9	3.9	2.0	1.74	1.96	1.92	1.50	1.71	1.50	1.15	2.03	.4	.09	2.6	.66	1.5	.38	.85	.89	1.01
			210	5.1	3.2	1.9	1.25	1.42	1.34	1.15	1.24	1.00	.75	1.45	.4	.13	2.3	.71	1.2	.37	.86	.88	1.00
			250	5.6	3.2	2.4	1.10	1.22	1.19	1.01	1.10	.90	.76	1.25	.4	.12	2.2	.70	1.2	.37	.88	.90	1.00
			290	5.7	3.6	2.1	1.47	1.60	1.61	1.35	1.48	1.27	1.00	1.65	.4	.10	2.5	.69	1.2	.33	.89	.92	1.00
			330	4.5	2.5	2.0	1.35	1.50	1.45	1.25	1.35	1.35	.90	1.50	.1	.03	1.7	.70	1.0	.40	.90	.90	1.00
			370	3.9	1.8	2.1	1.14	1.25	1.30	.96	1.13	1.15	.72	1.32	.0	.00	1.2	.68	.5	.28	.86	.91	1.01
			410	4.2	2.1	2.1	.98	1.12	1.16	.81	.98	.92	.34	1.20	.1	.04	1.4	.68	.6	.29	.82	.87	.99
			450	3.8	1.8	2.0	.82	.91	.86	.80	.83	.65	.65	.92	.3	.16	1.3	.72	.7	.39	.90	.91	.99
Mean of 10 curves	......	......	......	5.0	3.0	2.04	1.32	......	......	......	......	......	......	......	......	.10	......	.71	......	.37	.87	.89	1.00

Vertical velocity measurements—Continued.

MAUMEE RIVER AT SHERWOOD, OHIO.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 11[b]	3.34	2.79	50	......	2.6	0.7	0.69	0.76	0.73	0.65	0.69	0.61	0.51	0.76	0.3	0.11	1.8	0.71	1.0	0.38	0.86	0.91	1.00
			70	......	2.3	.6	.69	.74	.72	.64	.68	.63	.50	.75	.2	.11	1.6	.70	.9	.39	.92	.93	1.01
			90	......	2.6	.5	.68	.71	.71	.68	.70	.68	.56	.72	.4	.13	1.7	.65	.9	.35	.95	.96	.98
			110	......	2.5	.5	.82	.90	.88	.75	.82	.76	.48	.91	.2	.08	1.8	.69	.9	.36	.90	.91	1.00
			130	......	2.4	.6	.81	.83	.89	.72	.80	.90	.62	.90	......	......	1.4	.58	.2	.06	.90	.98	1.00
			160	......	2.3	.5	.93	.98	.93	.92	.92	.83	.72	.98	.5	.22	1.8	.78	1.2	.52	.95	.95	1.00
			180	......	2.7	.6	.87	.91	.98	.73	.86	.97	.57	.99	......	......	1.6	.59	.4	.15	.88	.96	1.02
			200	......	2.6	.6	.78	.82	.86	.69	.78	.82	.58	.86	......	......	1.6	.62	.6	.23	.91	.95	1.00
			220	......	2.7	.6	.84	.90	.92	.73	.82	.78	.54	.93	.2	.05	1.8	.67	.9	.33	.90	.93	1.02
			240	......	2.3	.7	.70	.72	.68	.68	.68	.58	.62	.72	.7	.31	1.8	.78	1.1	.48	.97	.97	1.03
			260	......	2.4	.5	.82	.85	.83	.81	.82	.73	.75	.85	.4	.18	1.8	.75	1.1	.46	.97	.96	1.00
Mean of 11 curves	......	......	......	......	2.5	.58	.78	......	......	......	......	......	......	......	......	.11	......	.68	......	.34	.92	.95	1.01

MOHAWK RIVER AT SCHUYLER STREET BRIDGE, UTICA, N. Y.[c]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Max. thread In feet.	In per cent of depth.	Coef. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1902.																							
December 10	16.4	......	20	11.0	10.5	0.50	0.74	0.91	0.60	0.80	0.70	0.55	0.50	0.95	3.9	0.37	9.0	0.86	6.0	0.57	0.78	0.81	1.06
			30	11.6	11.1	.50	.90	1.08	.68	1.00	.84	.56	.73	1.10	4.0	.36	10.4	.93	6.5	.59	.82	.83	1.07
			40	11.4	10.9	.50	.88	1.10	.62	1.02	.82	.52	.68	1.15	3.8	.36	9.8	.90	7.0	.64	.76	.80	1.07
			50	11.0	10.5	.50	1.03	1.22	.88	1.10	.99	.74	.83	1.23	3.0	.28	8.9	.85	5.6	.53	.84	.84	1.04
			60	9.6	9.1	.50	.97	1.20	.90	1.00	.95	.10	.71	1.20	2.0	.22	7.6	.84	4.5	.49	.81	.81	1.02
Mean of 5 curves	......	......	......	10.9	10.4	.50	.90	......	......	......	......	......	......	......	......	.32	......	.88	......	.56	.80	.82	1.05
December 11	16.0	......	10	9.2	8.7	.50	.45	.58	.52	.38	.45	.35	.28	.60	.8	.09	6.2	.71	3.0	.34	.75	.78	1.00
			20	11.0	10.5	.50	1.00	1.20	1.20	.75	.98	.62	.38	1.28	1.0	.10	6.8	.65	3.5	.33	.78	.83	1.02
			30	11.8	11.3	1.15	.50	1.38	1.10	1.10	1.10	1.05	.65	1.38	2.6	.23	8.6	.76	5.7	.51	.83	.83	1.05

[a] Gravel bed.

[b] Ice rough.

[c] Earth bed very smooth.

Vertical velocity measurements—Continued.

MOHAWK RIVER AT SCHUYLER STREET BRIDGE, UTICA, N. Y.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1902.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
December 11.	16.0	......	40	11.4	10.9	0.50	1.20	1.40	1.30	1.04	1.17	0.56	0.65	1.45	2.1	0.19	7.6	0.70	4.3	0.40	0.83	0.86	1.03
			50	10.9	10.4	.50	1.40	1.48	1.42	1.10	1.26	1.05	.70	1.55	2.0	.20	8.3	.80	4.0	.38	.90	.95	1.11
			60	10.1	9.6	.50	1.28	1.40	1.26	1.12	1.19	1.10	.75	1.40	2.2	.23	6.7	.70	5.0	.52	.91	.91	1.08
			70	9.8	9.3	.50	1.05	1.32	1.12	1.00	1.06	.48	.50	1.32	1.5	.16	7.2	.78	4.5	.48	.80	.80	.99
			80	9.3	8.8	.50	.92	1.10	1.00	.75	.88	.65	.20	1.10	1.9	.22	6.0	.68	3.5	.40	.84	.84	1.05
Mean of 8 curves	......	......	......	10.4	9.9	.50	1.06	......	......	......	......	......	......	......	......	.18	......	.72	......	.42	.83	.85	1.04

OLENTANGY RIVER AT COLUMBUS, OHIO.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Max. In feet.	Max. In per cent of depth.	Coef. Maximum.	Coef. 0.5 depth.	Coef. $\frac{0.2+0.8}{2}$ depth.
1906.																							
February 13	6.77	6.22	20	2.5	2.0	0.5	0.16	0.19	0.22	0.10	0.16	0.17	0.00	0.22	......	......	1.2	0.62	0.6	0.30	0.73	0.84	1.00
			30	4.3	3.8	.5	.34	.38	.38	.30	.34	.32	.20	.39	0.2	0.05	2.5	.65	1.3	.34	.87	.90	1.00
			40	5.0	4.5	.5	.29	.30	.29	.28	.28	.27	.27	.30	.7	.16	2.8	.62	1.8	.40	.97	.97	1.02
			60	4.6	4.0	.6	.22	.24	.26	.17	.22	.23	.12	.27	......	......	2.5	.62	1.0	.25	.82	.92	1.02
			80	4.4	3.8	.6	.15	.18	.17	.14	.16	.10	.10	.18	.5	.13	2.7	.71	1.6	.41	.83	.83	.97
Mean of 5 curves	......	......	......	4.2	3.6	.54	.23	......	......	......	......	......	......	......	......	.07	......	.64	......	.34	.84	.89	1.00

[a] Gravel and silt bed.

Vertical velocity measurements—Continued.

RAQUETTE RIVER AT MASSENA SPRINGS, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1905.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 28	10.31	......	40	11.6	9.1	2.5	3.24	3.56	3.40	3.15	3.28	......	2.20	3.58	1.0	0.11	6.9	0.76	4.0	0.44	0.99	0.91	0.99
			60	11.9	10.1	1.8	3.34	3.72	3.80	2.85	3.32	......	1.73	3.86	.0	......	6.8	.67	3.3	.33	.96	.90	1.01
			80	11.1	9.4	1.7	3.28	3.74	3.42	3.25	3.33	......	2.24	3.78	1.5	.16	7.4	.79	3.8	.40	.99	.88	.99
			100	12.3	10.4	1.9	3.04	3.59	3.40	2.62	3.01	......	1.51	3.61	.7	.07	7.3	.70	4.5	.43	.99	.85	1.01
			120	12.1	10.2	1.9	3.26	3.60	3.50	3.00	3.25	......	2.02	3.64	1.0	.10	7.3	.72	3.6	.36	.99	.90	1.00
			140	13.8	12.0	1.75	3.34	3.76	3.38	3.28	3.33	......	2.15	3.76	2.4	.20	6.3	.52	5.8	.48	1.00	.89	1.00
Mean of 6 curves	......	......	......	12.1	10.2	1.92	3.25	......	......	......	......	......	......	......	......	.11	......	.69	......	.41	.99	.89	1.00
March 29	8.77	......	40	10.0	8.0	2.0	2.84	3.34	3.00	2.58	2.79	......	1.76	3.36	1.2	.15	5.8	.72	3.5	.44	.85	.85	1.02
			60	10.4	8.9	1.5	3.04	3.43	3.25	2.92	3.08	......	2.22	3.50	1.4	.15	6.6	.75	3.3	.37	.87	.89	.99
			80	9.9	8.4	1.5	2.87	3.35	2.95	2.82	2.88	......	1.28	3.37	1.6	.16	6.6	.79	3.5	.42	.85	.86	1.00
			100	10.5	8.8	1.7	2.75	3.32	2.80	2.60	2.70	......	1.52	3.36	1.6	.19	6.6	.75	3.8	.43	.82	.83	1.02
			120	10.6	9.1	1.5	3.30	3.66	3.45	3.15	3.30	......	2.44	3.73	1.5	.17	6.7	.74	3.2	.35	.88	.90	1.00
			140	12.4	10.9	1.5	3.30	3.75	3.35	3.30	3.32	......	2.00	3.75	2.0	.18	8.6	.79	5.2	.48	.88	.88	.99
Mean of 6 curves	......	......	......	10.6	7.4	1.62	3.02	......	......	......	......	......	......	......	......	.17	......	.76	......	.42	.86	.87	1.00
March 30	9.73	......	40	10.9	9.0	1.9	3.76	4.08	4.45	3.15	3.80	......	2.44	4.48	.3	.29	5.6	.62	2.2	.24	.84	.92	.99
			60	11.3	10.3	1.0	3.51	3.74	3.55	3.40	3.48	......	2.84	3.74	1.8	.17	7.6	.74	4.9	.48	.94	.94	1.01
			80	10.7	9.2	1.5	3.19	3.51	3.15	3.28	3.22	......	2.59	3.51	2.0	.22	7.7	.84	5.0	.54	.89	.91	.99
			100	11.3	10.3	1.0	3.23	3.99	3.08	3.18	3.13	......	1.96	3.99	2.4	.23	8.0	.78	5.2	.50	.81	.81	1.03
			120	11.6	10.6	1.0	3.58	4.24	3.32	3.70	3.51	......	2.76	4.27	2.8	.26	8.8	.83	5.7	.54	.84	.84	1.02
Mean of 5 curves	......	......	......	11.2	9.9	1.28	3.45	......	......	......	......	......	......	......	......	.23	......	.76	......	.46	.86	.88	1.01

[a] Coarse gravel bed.

Vertical velocity measurements—Continued.

RONDOUT CREEK AT ROSENDALE, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1901.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
December 6[b]	6.80	......	50	5.6	5.4	0.2	0.47	0.62	0.45	0.48	0.46	0.08	0.21	0.62	1.1	0.20	4.4	0.82	2.8	0.52	0.76	0.76	1.02
1902.																							
January 14	7.00	......	40	4.8	4.0	.8	.72	.78	.48	.79	.64	.07	.67	.96	1.4	.35	......	......	2.5	.62	.75	.92	1.12
			50	6.4	6.0	.4	.82	.90	.80	.83	.82	.65	.62	.90	1.4	.23	4.9	.82	3.0	.50	.91	.91	1.00
			60	6.4	6.0	.4	.94	1.17	.78	1.04	.91	.38	.65	1.18	1.8	.30	5.2	.87	3.5	.58	.80	.80	1.03
Mean of 4 curves	......	......	......	5.8	5.3	.45	.74	......	......	......	......	......	......	......	......	.27	......	.88	......	.76	.80	.85	1.04
1906.																							
February 17[c]	5.15	......	50	6.7	4.9	.75	.32	.44	.46	.38	.42	.38	.00	.46	......	......	4.4	.91	1.5	.31	.70	.74	.76
			60	7.1	4.3	.80	.26	.48	.40	.35	.38	.26	.00	.46	......	......	3.8	.90	2.3	.54	.58	.55	.70
			70	7.5	5.5	.72	.37	.55	.52	.38	.45	.46	.00	.55	......	......	4.5	.82	2.4	.43	.68	.62	.82
Mean of 3 curves	......	......	......	7.1	4.9	.76	.32	......	......	......	......	......	......	......	......	......	......	.87	......	.42	.65	.63	.76
February 17	5.15	......	80	7.7	7.1	.72	.51	.56	.60	.44	.52	.50	.26	.60	......	......	5.0	.70	1.9	.27	.85	.91	.98
			90	7.7	7.1	.78	.56	.65	.77	.30	.54	.66	.00	.78	......	......	4.4	.61	1.4	.20	.72	.86	1.04
			100	6.4	5.8	.75	.60	.65	.70	.50	.60	.56	.36	.70	.1	.02	3.8	.61	1.4	.25	.85	.92	1.00
Mean of 3 curves	......	......	......	7.3	6.7	.75	.55	......	......	......	......	......	......	......	......	......	......	.65	......	.24	.80	.89	1.00

[a] Rock bed.

[b] Ice cover very rough—broken and tilted.

[c] Needle ice on bed of stream.

Vertical velocity measurements—Continued.

WALLKILL RIVER AT NEWPALTZ, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1901.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
December 11	11.5	......	53	9.9	9.2	0.70	2.45	2.75	2.45	2.51	2.48	1.85	1.80	2.76	2.4	0.26	7.5	0.82	5.0	0.54	0.89	0.89	0.99
			64	10.7	10.0	.70	2.17	2.65	2.98	1.22	2.10	2.24	.20	3.25	......	......	6.0	.60	2.4	.24	.67	.82	1.03
			75	12.2	11.5	.70	2.64	3.03	2.98	2.25	2.61	2.15	1.35	3.23	1.2	.10	7.9	.69	3.8	.33	.82	.87	1.01
			85	12.3	11.6	.70	2.60	2.98	2.96	2.25	2.60	2.25	1.20	3.13	.8	.07	8.1	.70	4.3	.37	.83	.87	1.01
Mean of 4 curves				11.3	10.6	.70	2.46									.10		.70		.37	.80	.86	1.01
December 19[b]	13.7	......	115	18.0	13.5	4.50	2.44	2.97	2.24	2.70	2.47	.55	1.04	3.00	3.5	.26	12.0	.89	7.5	.56	.81	.82	.99
			95	16.0	16.0	.05	3.48	4.00	3.22	3.74	3.48	2.35	2.25	4.14	4.4	.27	13.7	.86	9.5	.59	.84	.87	1.00
			85	15.6	15.6	.05	3.40	3.94	3.13	3.60	3.36	2.15	2.20	3.96	4.3	.28	13.4	.86	8.5	.54	.86	.86	1.01
			75	14.5	13.5	1.00	2.63	3.10	2.44	2.89	2.66	.85	2.30	3.13	3.5	.26	12.4	.92	7.6	.56	.84	85	.99
Mean of 4 curves				16.0	14.6	1.40	2.98									.27		.88		.56	.84	85	1.00
1902.																							
January 21	7.24	......	50	......	3.4	[c]1.20	.81	.88	.90	.70	.80	.68	.10	.95	.4	.10	2.5	.74	1.2	.35	.85	.92	1.01
			70	......	5.0	......	1.01	1.10	1.14	.85	1.00	.96	.36	1.18	.1	.02	3.4	.68	1.8	.36	.85	.92	1.00
			80	......	5.8	......	1.01	1.17	1.07	.94	1.00	.66	.55	1.19	.9	.15	4.3	.74	2.1	.36	.84	.86	1.01
			90	......	6.6	......	1.02	1.20	1.22	.88	1.05	.45	.50	1.25	.8	.12	4.7	.71	2.2	.33	.82	.85	.97
			100	......	7.8	......	1.08	1.25	1.18	.96	1.07	.70	.50	1.27	.8	.10	5.7	.73	3.2	.41	.85	.87	1.00
			110	......	8.4	......	.39	.50	.43	33	.38	.22	.14	.52	1.4	.17	6.0	.72	3.4	.41	.75	.78	1.02
Mean of 6 curves					6.2	1.20	.89									.11		.72		.37	.83	.87	1.00
January 23[d]	17.33	......	30	14.4	13.0	1.40	2.20	2.58	1.96	2.37	2.16	1.58	1.40	2.65	4.0	.31	10.8	.83	8.0	.62	.83	.85	1.02
			40	15.4	14.0	1.40	3.13	3.62	3.23	3.13	3.18	1.60	1.30	3.62	2.2	.16	11.2	.80	6.5	.47	.86	.87	.98
			50	18.0	17.0	1.00	3.63	4.00	3.70	3.72	3.71	1.45	1.60	4.00	3.1	.18	14.7	.87	7.5	.44	.91	.91	.98
			60	16.0	15.2	.80	4.10	4.24	4.21	4.02	4.12	2.70	2.20	4.28	2.3	.15	11.6	.76	4.5	.30	.96	.97	1.00
			70	21.6	20.8	.80	4.02	4.38	4.19	4.11	4.15	2.10	1.60	4.38	2.5	.12	17.4	.84	10.5	.51	.92	.92	.97
			80	22.2	21.5	.70	3.96	4.30	4.21	3.88	4.04	2.40	2.00	4.32	2.1	.10	16.4	.77	8.5	.40	.92	.92	.98

[a] Clay and coarse gravel bed.
[b] Ice very rough and broken.
[c] Mean.
[d] Gage at beginning—18.26; at ending—16.40.

Vertical velocity measurements—Continued.

WALLKILL RIVER AT NEWPALTZ, N. Y.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.						
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1902.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
January 23	17.33	......	90	22.2	21.5	0.70	3.93	4.27	4.23	3.63	3.93	2.80	2.00	4.37	1.5	0.07	15.0	0.70	8.0	0.37	0.90	0.92	1.00
			100	21.6	20.8	.80	3.89	4.20	3.90	4.00	3.95	2.00	2.20	4.20	4.0	.19	18.0	.87	10.0	.48	.93	.93	.98
			110	23.2	22.4	.80	3.73	4.17	3.82	3.80	3.81	2.20	2.00	4.18	3.8	.17	17.4	.78	9.5	.42	.89	.90	.98
			120	16.8	16.0	.80	2.77	3.22	3.20	2.50	2.85	1.60	1.10	3.45	2.0	.12	11.4	.71	5.2	.33	.80	.87	.97
Mean of 10 curves	......	......	......	19.1	18.2	.92	3.54	......	......	......	......	......	......	......	......	.16	......	.79	......	.43	.89	.91	.99
January 31	9.07	......	40	6.8	5.8	1.00	1.52	1.70	1.60	1.42	1.51	1.20	.92	1.73	.9	.15	4.3	.74	2.2	.38	.88	.90	1.00
			50	6.2	5.1	1.00	1.86	2.06	2.09	1.62	1.85	1.60	.96	2.13	.3	.06	3.4	.69	1.6	.31	.87	.90	1.00
			60	5.1	4.1	1.00	1.74	2.06	2.09	1.35	1.72	1.48	.46	2.15	.2	.05	2.9	.71	1.3	.32	.81	.84	1.01
			70	8.8	7.8	1.00	2.08	2.35	2.34	1.83	2.08	1.72	.95	2.43	.7	.09	5.3	.68	2.6	.33	.86	.89	1.00
			80	8.8	7.8	1.00	2.14	2.35	2.38	2.02	2.20	1.28	1.30	2.45	.9	.12	5.6	.72	2.4	.31	.87	.91	.98
			90	10.0	9.0	1.00	2.09	2.37	2.38	1.83	2.10	1.15	1.15	2.46	1.0	.11	6.2	.69	3.0	.33	.86	.88	1.00
			100	11.5	10.3	1.20	2.24	2.48	2.28	2.24	2.26	1.62	1.35	2.48	1.4	.14	7.9	.77	4.5	.44	.90	.90	.99
Mean of 7 curves	......	......	......	8.2	7.1	1.03	1.95	......	......	......	......	......	......	......	......	.10	......	.71	......	.34	.86	.89	1.00
February 10	7.78	......	80	7.5	6.5	1.00	1.43	1.61	1.54	1.32	1.43	.95	.88	1.68	1.0	.15	4.6	.71	2.5	.38	.85	.89	1.00
			90	8.5	7.5	1.00	1.43	1.58	1.66	1.22	1.44	.90	.90	1.74	.7	.09	4.8	.64	2.2	.29	.82	.91	.99
			100	9.6	8.6	1.00	1.53	1.80	1.56	1.43	1.50	1.12	.90	1.81	1.6	.19	6.3	.73	4.0	.46	.84	.84	1.02
			110	10.1	8.9	1.20	.78	.82	.50	.96	.73	.28	.61	.98	4.0	.45	8.4	.94	6.6	.74	.80	.95	1.07
Mean of 4 curves	......	......	......	8.9	7.9	1.05	1.29	......	......	......	......	......	......	......	......	.22	......	.76	......	.46	.82	.90	1.02
February 24	7.35	......	40	5.7	3.5	a2.20	.53	.63	.60	.45	.52	.25	.26	.64	.4	.11	2.4	.70	2.4	.69	.83	.84	1.02
			80	7.3	5.3	2.00	.84	.98	.92	.84	.72	.65	.45	1.02	1.1	.21	3.4	.64	2.0	.38	.82	.86	1.00
			90	8.0	6.0	2.00	.86	1.00	1.02	.72	.87	.60	.50	1.08	.4	.07	4.0	.67	2.0	.33	.80	.86	.99
			100	9.0	7.0	2.00	.98	1.12	1.05	.84	.94	.69	.50	1.13	.9	.13	5.0	.71	2.8	.40	.87	.87	1.04
			110	9.3	7.0	2.30	.53	.61	.58	.44	.51	.42	.24	.63	.6	.09	4.8	.69	2.6	.37	.84	.87	1.04
Mean of 5 curves	......	......	......	7.9	5.8	2.10	.75	......	......	......	......	......	......	......	......	.12	......	.68	......	.43	.83	.86	1.02

a Thickness of ice as given includes considerable water above ice.

Vertical velocity measurements—Continued.

WALLKILL RIVER AT NEWPALTZ, N. Y.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1903.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
January 7	11.2	......	60	7.6	6.8	0.80	2.23	2.51	2.77	1.66	2.22	2.00	1.00	2.80	1.2	0.22	4.2	0.61	1.8	0.26	0.80	0.89	1.00
			80	11.1	10.3	.80	2.54	2.74	2.91	2.25	2.58	1.60	1.80	2.94	.6	.06	7.0	.68	2.9	.28	.86	.93	.99
			90	11.6	10.8	.80	2.38	2.57	2.68	2.20	2.44	1.30	1.70	2.72	1.0	.09	7.6	.70	3.1	.28	.87	.93	.98
			110	13.1	12.3	.80	2.52	2.82	2.63	2.58	2.60	1.74	1.70	2.83	1.8	.15	10.0	.81	5.2	.42	.89	.90	.97
Mean of 4 curves	......	......	......	10.8	10.0	.80	2.42	......	......	......	......	......	......	......	......	.13	......	.70	......	.31	.86	.91	.99
February 10	10.8	......	25	......	4.8	1.33	1.29	1.42	1.38	1.14	1.26	1.00	.82	1.42	.2	.04	3.2	.67	2.2	.46	.91	.91	1.02
			40	......	8.0	1.00	2.26	2.44	2.20	2.30	2.25	1.86	1.95	2.43	2.0	.25	6.6	.82	4.0	.50	.93	.92	1.00
			60	......	6.0	1.00	2.17	2.59	2.55	1.71	2.15	1.70	.90	2.65	.4	.07	4.1	.68	2.1	.35	.82	.84	1.01
			80	......	9.6	1.00	2.53	2.78	2.79	2.32	2.56	1.80	1.50	2.89	.8	.08	6.6	.69	2.7	.29	.88	.91	.99
			110	......	11.8	1.00	2.65	3.00	2.81	2.52	2.66	1.98	.80	3.02	1.4	.12	9.1	.77	5.2	.44	.88	.88	1.00
Mean of 5 curves	......	......	......	......	8.0	1.06	2.18	......	......	......	......	......	......	......	......	.11	......	.72	......	.41	.88	.89	1.00
February 26	8.85	......	25	5.2	5.2	1.20	.59	.63	.72	.52	.62	.42	.15	.76	.3	.06	2.4	.46	2.3	.44	.78	.94	.95
			40	7.0	5.8	1.20	1.20	1.31	1.40	1.15	1.28	1.00	.00	1.43	.4	.06	4.2	.72	1.2	.21	.84	.92	.94
			60	5.2	4.2	1.00	1.12	1.40	1.42	.73	1.08	.90	.00	1.53	.3	.07	2.8	.67	1.4	.34	.73	.80	1.04
			80	8.8	7.8	1.00	1.43	1.58	1.58	1.30	1.44	1.15	.65	1.68	.6	.08	5.8	.74	2.8	.36	.85	.90	.99
			100	10.2	9.2	1.00	1.41	1.57	1.60	1.20	1.40	1.15	.62	1.68	.6	.07	6.4	.70	3.2	.35	.84	.90	1.00
			110	11.2	10.5	.70	1.87	2.04	1.80	1.92	1.86	1.30	1.27	2.20	2.7	.26	8.7	.83	6.2	.59	.85	.92	1.00
			120	8.5	7.9	.60	.68	.80	.70	.68	.69	.28	.20	.80	1.5	.19	6.3	.86	3.4	.43	.85	.85	.99
Mean of 7 curves	......	......	......	8.0	7.2	.96	1.20	......	......	......	......	......	......	......	......	.11	......	.70	......	.39	.82	.89	.99

Vertical velocity measurements—Continued.

WEST CANADA CREEK AT TWIN ROCK BRIDGE, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 9[b]	3.03	......	25	3.6	2.4	1.25	1.58	1.78	1.71	1.48	1.60	1.00	0.98	1.81	0.3	0.14	1.8	0.74	1.0	0.41	0.87	0.89	0.99
			30	3.8	2.6	1.30	1.70	1.77	1.85	1.53	1.69	1.86	1.23	1.86	......	......	1.6	.62	.0	......	.92	.96	1.00
			40	3.6	2.3	1.32	2.12	2.30	2.35	1.89	2.12	2.23	1.47	2.39	......	......	1.5	.65	.8	.32	.89	.92	1.00
			50	5.9	4.7	1.34	1.45	2.03	1.67	1.15	1.41	.86	.00	2.06	.6	.13	3.5	.75	2.0	.43	.70	.71	1.03
			60	6.5	5.0	1.48	.65	.72	.73	.54	.64	.50	.38	.76	.5	.10	3.0	.60	1.7	.34	.86	.90	1.02
February 10	3.03	......	120	5.0	3.4	1.58	1.10	1.13	1.16	1.02	1.09	1.16	.76	1.16	......	......	2.1	.62	.0	......	.95	.97	1.01
			130	4.2	2.6	1.60	1.28	1.32	1.34	1.21	1.28	1.23	1.12	1.35	.2	.06	1.6	.62	.7	.27	.95	.97	1.00
			140	4.2	2.6	1.75	.95	1.03	.95	.93	.94	.80	.84	1.04	.5	.19	2.0	.77	1.0	.39	.91	.92	1.01
Mean of 8 curves	......	......	......	5.2	3.2	1.45	1.35	......	......	......	......	......	......	......	......	.08	......	.67	......	.27	.88	.91	1.01
1903.																							
February 21	3.8	......	20	3.8	2.3	1.5	1.65	1.84	1.70	1.56	1.63	1.53	.66	1.84	.3	.13	1.8	.78	1.4	.59	.90	.90	1.01
			25	4.1	2.6	1.5	1.57	1.70	1.79	1.26	1.52	1.61	.85	1.82	......	......	1.6	.62	.8	.31	.86	.92	1.03
			30	4.2	2.7	1.5	1.50	1.65	1.74	1.21	1.48	1.40	.84	1.76	.1	.04	1.5	.56	.8	.32	.85	.91	1.01
			35	4.2	2.7	1.5	1.65	1.84	1.80	1.51	1.66	1.46	.88	1.86	.1	.04	2.1	.76	1.0	.37	.90	.90	.99
			40	4.2	2.7	1.5	1.82	2.12	1.97	1.54	1.76	1.58	.92	2.18	.4	.13	1.9	.70	1.0	.39	.85	.86	1.03
			45	4.0	2.5	1.5	1.83	2.04	2.17	1.40	1.78	1.74	.90	2.24	.0	.02	1.5	.61	.8	.30	.82	.90	1.03
			50	3.9	2.2	1.75	2.18	2.30	2.30	1.97	2.14	2.00	1.69	2.34	.0	.02	1.5	.70	.8	.37	.93	.95	1.02
			55	3.8	2.0	1.75	2.22	2.31	2.38	1.99	2.18	2.32	1.54	2.38	......	......	1.3	.62	.5	.24	.93	.96	1.02
			60	4.0	2.5	1.5	2.00	2.19	2.45	1.56	2.00	2.30	.88	2.35	......	......	1.6	.63	.5	.20	.85	.91	1.00
Mean of 9 curves	......	......	......	4.0	2.5	1.56	1.82	......	......	......	......	......	......	......	......	.04	......	.66	......	.34	.86	.91	1.02

[a] Coarse gravel bed.

[b] Needle ice on under surface of ice.

Vertical velocity measurements—Continued.

WINOOSKI RIVER AT RICHMOND, VT.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from inirial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1905.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 3 [a]	5.45	2.70	5	3.3	1.2	2.6	1.20	1.52	1.23	1.13	1.18	0.70	0.68	1.52	0.2	0.17	0.9	0.75	0.5	0.41	0.79	0.79	1.02
			10	4.0	1.9	2.5	1.78	2.02	2.09	1.50	1.80	1.20	.88	2.15	.2	.10	1.3	.69	.6	.32	.83	.88	.99
			15	3.9	1.8	2.4	2.09	2.34	2.27	1.92	2.10	1.72	1.02	2.36	.2	.06	1.3	.72	.7	.39	.89	.89	1.00
			20	3.6	1.9	2.25	2.29	2.74	2.54	2.00	2.27	1.55	.98	2.76	.2	.10	1.4	.74	.8	.42	.83	.84	1.01
			25	3.6	1.6	2.2	2.45	2.88	2.74	2.13	2.44	1.50	1.23	2.95	.1	.06	1.1	.69	.7	.44	.83	.85	1.01
			30	3.5	1.8	2.1	2.32	2.81	2.42	2.14	2.28	1.25	1.45	2.83	.3	.17	1.3	.72	.8	.44	.82	.83	1.02
			35	3.4	1.6	2.2	2.04	2.58	2.42	1.62	2.02	.90	.80	2.80	.2	.12	1.1	.69	.6	.38	.73	.79	1.01
			40	3.4	1.4	2.4	1.97	2.45	2.45	1.48	1.96	1.33	.25	2.53	.1	.07	1.0	.72	.5	.36	.78	.80	1.00
			45	3.4	1.6	2.1	2.05	2.50	2.32	1.70	2.01	1.13	1.09	2.65	.2	.12	1.0	.63	.5	.31	.77	.82	1.02
			50	3.3	2.0	1.5	1.70	2.55	2.35	.69	1.52	.62	.00	2.94	.2	.10	1.4	.70	.7	.35	.58	.67	1.12
			55	3.0	1.9	1.5	1.66	1.97	1.27	1.93	1.60	.83	1.20	2.22	.7	.37	1.7	.89	1.2	.63	.75	.84	1.04
			60	2.8	1.4	1.6	1.93	2.33	2.14	1.55	1.84	1.80	.78	2.33	.1	.07	1.0	.71	.7	.50	.83	.83	1.05
			65	2.2	.8	2.0	1.50	1.80	1.85	1.25	1.55	.56	.30	1.79	.1	.12	.6	.75	.2	.25	.84	.83	.97
Mean of 13 curves	......	......	......	3.3	1.6	2.10	1.92	......	......	......	......	......	......	......	......	.13	......	.72	......	.40	.79	.82	1.02
March 4 [a]	5.58	2.83	5	3.4	1.3	2.75	1.41	1.67	1.46	1.25	1.36	1.25	.76	1.67	.2	.15	1.0	.77	.6	.46	.84	.84	1.04
			10	4.0	1.8	2.75	2.00	2.25	2.24	1.74	1.99	1.65	1.00	2.32	.1	.06	1.2	.67	.6	.33	.86	.89	1.01
			15	4.0	2.0	2.55	2.27	2.51	2.45	2.03	2.24	2.15	1.40	2.53	.1	.05	1.4	.70	.8	.40	.90	.90	1.01
			20	4.0	2.0	2.3	2.63	2.97	2.87	2.39	2.63	2.33	1.23	3.03	.2	.10	1.4	.70	.7	.35	.87	.88	1.00
			25	3.7	1.7	2.35	2.60	3.25	2.77	2.23	2.50	1.72	1.20	3.24	.3	.18	1.2	.71	.8	.47	.80	.80	1.04
			30	3.8	2.0	2.1	2.25	2.92	2.37	2.01	2.19	1.00	1.25	2.95	.4	.20	1.5	.75	.9	.45	.76	.77	1.02
			35	3.6	1.6	2.25	2.58	3.18	2.73	2.18	2.46	2.13	1.25	3.20	.2	.12	1.2	.75	.8	.50	.81	.81	1.05
			40	3.8	1.6	2.3	2.36	2.57	2.96	1.87	2.42	1.58	1.20	2.97	.1	.06	1.0	.63	.4	.25	.79	.92	.98
			45	3.6	1.7	2.1	2.54	3.23	2.67	2.23	2.45	1.50	1.30	3.27	.3	.18	1.2	.70	.8	.47	.78	.79	1.04
			50	3.5	2.1	1.55	2.50	3.23	2.50	2.30	2.40	.35	1.70	3.53	.4	.19	1.6	.76	.8	.38	.71	.77	1.04
			55	3.3	1.9	1.55	2.65	3.02	3.17	2.17	2.67	2.43	.75	3.18	.00	.00	1.3	.68	.6	.32	.83	.88	.99
			60	3.0	1.5	1.6	2.39	2.90	2.75	1.85	2.30	2.10	1.00	2.98	.00	.00	1.0	.67	.6	.40	.80	.82	1.04
			65	2.6	1.0	2.0	1.83	2.10	2.04	1.62	1.83	1.70	.65	2.13	.10	.10	.7	.70	.4	.40	.86	.87	1.00
Mean of 13 curves	......	......	......	3.6	1.7	2.17	2.31	......	......	......	......	......	......	......	......	.11	......	.71	......	.40	.82	.84	1.02

[a] At section about one-half mile above bridge; gravel bed.

Vertical velocity measurements—Continued.

WINOOSKI RIVER AT RICHMOND, VT.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves. Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Depth of threads of mean velocity. Upper. In feet.	Upper. In per cent of depth.	Lower. In feet.	Lower. In per cent of depth.	Depth of thread of maximum velocity. In feet.	In per cent of depth.	Coefficients for reducing to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 9[a]	5.62	3.42	21	11.5	9.0	2.5	1.74	2.19	1.13	2.27	1.70	0.50	1.28	2.46	3.3	0.37	8.5	0.94	5.8	0.64	0.71	0.80	1.02
			30	10.0	7.0	3.0	2.10	2.82	2.44	2.04	2.24	.20	.30	2.86	1.2	.16	5.6	.79	2.8	.40	.74	.74	.94
			40	7.5	4.8	2.75	2.24	2.69	2.38	1.96	2.17	2.02	.94	2.70	.6	.12	3.5	.74	2.4	.52	.83	.83	1.03
			50	7.3	5.3	2.0	2.02	2.86	2.03	1.77	1.90	1.46	.56	3.00	1.1	.21	4.1	.77	3.0	.57	.68	.71	1.07
			60	6.9	4.9	2.0	1.93	2.59	1.76	2.04	1.90	.50	1.00	2.52	1.1	.22	4.1	.84	2.2	.45	.77	.77	1.02
			60	7.0	5.0	2.0	1.80	2.59	1.41	2.15	1.78	.40	.70	2.52	1.5	.30	4.2	.83	2.7	.54	.72	.72	1.01
Mean of 6 curves	......	......	......	8.6	6.2	2.45	1.99	......	......	......	......	......	......	......	......	.22	......	.81	......	.52	.74	.76	1.02

[a] At bridge; sand and gravel bed; ice cover very rough, broken, and tilted.

SUMMARIES OF VERTICAL VELOCITY CURVES.

The mean results from the vertical velocity curves (pp. 47–71) have been arranged in three groups—(1) 352 curves for smooth ice cover, (2) 51 curves for rough ice cover, (3) 13 curves for very rough ice cover. It will be noted that in some cases where gage heights were approximately the same for different sets of curves they have been combined. There is little difference between the results of groups 1 and 2, but as rough ice cover was reported for group 2, it seemed best not to include it in the larger list.

Summary of vertical velocity curves under ice cover.

SMOOTH ICE COVER.

River.	Station.	Number of curves.	Gage height to water surface.	Depth under ice.	Ice thickness.	Mean velocity.	Depth of threads of velocity.			Coefficient to reduce to mean velocity.			Bed of stream.
							Upper mean.	Lower mean.	Maximum.	Maximum.	0.5 depth.	0.2+0.8 depth / 2.	
			Feet.	*Feet.*	*Feet.*	*Ft. per sec.*							
Catskill	South Cairo, N. Y	4	2.82	2.7	0.98	0.44	0.06	0.70	0.31	0.80	0.88	0.98	Gravel.
Chemung	Chemung, N. Y	4	2.85	3.7	.51	.64	.16	.79	.46	.86	.85	1.02	Coarse gravel.
Connecticut	Orford, N. H	18	4.16	4.0	1.97	1.04	.11	.69	.37	.85	.88	1.00	Gravel and sand.
		12	± 4.1	4.1	1.91	.92	.07	.63	.25	.83	.92	.99	
		6	5.6	7.3	....	1.80	.12	.73	.37	.87	.89	.99	
Esopus	Kingston, N. Y	2	5.28	5.8	.10	.94	.16	.74	.52	.87	.87	1.02	Sand and gravel.
		8	5.60	3.4	.56	.80	.03	.63	.24	.76	.85	1.01	
		12	6.6	4.9	.10	1.19	.07	.69	.29	.82	.88	.98	
		8	7.0	5.0	.50	1.26	.08	.67	.36	.82	.86	.98	
Fish	Wallagrass, Me	8	3.91	2.5	1.40	.90	.07	.70	.36	.88	.89	1.00	Gravel.
		8	5.00	3.5	1.45	1.25	.14	.77	.43	.84	.86	.98	
Genesee	Mount Morris (Jones Bridge), N.Y.	20	5.9	3.8	.54	1.62	.07	.67	.34	.80	.85	1.01	Coarse gravel.
Genesee	Rochester, N. Y	11	1.42	6.6	.45	.45	.09	.72	.44	.84	.86	.99	Do.
		19	1.55	3.8	.43	.89	a.01	.70	.33	.82	.87	1.00	
Kennebec	North Anson, Me	4	3.40	2.7	....	2.27	....	.63	.19	.82	.92	1.00	Gravel.
		12	3.48	2.6	1.30	1.17	.04	.66	.30	.87	.91	.02	
		15	3.55	1.6	2.15	1.87	.18	.77	.45	.81	.82	1.01	
		19	4.17	2.5	1.91	1.30	.07	.69	.34	.86	.90	1.00	
		10	4.70	3.0	2.04	1.32	.10	.71	.37	.87	.89	1.00	
		9	4.77	2.9	2.34	1.33	.08	.70	.32	.87	.90	.98	
		23	5.30	3.2	2.00	1.61	.12	.70	.12	.83	.86	1.01	
Mohawk	Utica, N. Y	13	b 16.2	10.1	.50	1.00	.21	.78	.47	.82	.84	1.04	Earth, very smooth.
Raquette	Massena Springs, N. Y	17	9.6	9.2	1.60	3.24	.17	.74	.43	.90	.88	1.00	Coarse gravel.
Rondout Creek	Rosendale, N. Y	3	5.15	6.7	.75	.55	(c)	.65	.24	.80	.89	1.00	Rock.
Wallkill	Newpaltz, N. Y	11	7.3	6.0	± 1.2	.83	.11	.70	.40	.83	.87	1.01	Clay and coarse gravel.
		4	7.78	7.9	1.05	1.29	.22	.76	.16	.82	.90	1.02	
		14	8.95	7.2	1.00	1.57	.10	.70	.36	.84	.89	1.00	
		13	11.2	9.5	.85	2.35	.11	.71	.36	.85	.89	1.00	
		10	17.33	18.2	.92	3.54	.16	.79	.43	.89	.91	.99	

a Upper thread of mean velocity at 4 curves only.

b Below reference point.

c Upper thread of mean velocity for 1 curve only.

Summary of vertical velocity curves under ice cover—Continued.

SMOOTH ICE COVER—Continued.

River.	Station.	Number of curves.	Gage height to water surface.	Depth under ice.	Ice thickness.	Mean velocity.	Depth of threads of velocity. Upper mean.	Lower mean.	Maximum.	Coefficient to reduce to mean velocity. Maximum.	0.5 depth.	$\frac{0.2+0.8 \text{ depth}}{2}$	Bed of stream.
			Feet.	*Feet.*	*Feet.*	*Ft. per sec.*							
West Canada Creek	Twin Rock Bridge, N. Y	9	3.8	2.5	1.50	1.82	0.04	0.66	0.34	0.86	0.91	1.02	Coarse gravel.
Winooski	Richmond, Vt	26	5.5	1.6	2.10	2.12	.12	.72	.40	.80	.83	1.02	Gravel.
Mean of 352 curves							.10	.71	.37	.839	.878	1.002	
Highest							.22	.79	.52	.90	.92	1.04	
Lowest							.00	.63	.19	.76	.82	.98	

ROUGH ICE COVER.

River.	Station.	Number of curves.	Gage height to water surface.	Depth under ice.	Ice thickness.	Mean velocity.	Upper mean.	Lower mean.	Maximum.	Maximum.	0.5 depth.	$\frac{0.2+0.8 \text{ depth}}{2}$	Bed of stream.
Connecticut	Orford, N. H	7	5.59	4.6	1.71	1.08	0.08	0.70	0.37	0.86	0.88	1.00	Gravel and sand.
		7	6.00	4.9	1.69	1.11	.09	.70	.39	.84	.88	1.00	
		21	6.70	5.8	1.66	1.23	.14	.74	.42	.86	.88	1.00	
Des Moines	Keosauqua, Iowa	5	2.45	4.8	.46	1.58	.13	.73	.40	.86	.88	1.00	Gravel.
Maumee	Sherwood, Ohio	11	3.34	2.5	.58	.78	.11	.68	.34	.92	.95	1.01	Do.
Mean of 51 curves							.11	.71	.38	.868	.894	1.002	
Highest							.14	.74	.42	.92	.95	1.01	
Lowest							.08	.68	.34	.84	.88	1.00	

VERY ROUGH ICE COVER, BROKEN AND TILTED.

River.	Station.	Number of curves.	Gage height to water surface.	Depth under ice.	Ice thickness.	Mean velocity.	Upper mean.	Lower mean.	Maximum.	Maximum.	0.5 depth.	$\frac{0.2+0.8 \text{ depth}}{2}$	Bed of stream.
Rondout Creek	Rosendale, N. Y	4	±7.0	5.3	0.45	0.74	0.27	+[a]0.88	0.56	0.80	0.85	1.04	Rock.
Wallkill	Newpaltz, N. Y	4	13.7	14.6	1.40	2.98	.27	.88	.56	.84	.85	1.00	Clay and coarse gravel.
Winooski	Richmond, Vt	5	5.62	6.2	±2.5	1.99	.22	.81	.52	.74	.76	1.02	Sand and gravel.
Mean of 13 curves				8.7	1.45	1.90	.25	.86	.55	.79	.82	1.02	

[a] No lower mean thread of velocity for 1 curve.

FORM OF VERTICAL VELOCITY CURVE.

For an ideal cross section and length of river, the difference in velocity at different points in a vertical section is due to the difference in resistance to flow met with by the filaments of water at different depths. If no resistances of any kind existed, the vertical curve of velocity would be a straight line normal to the surface of the stream. If bed friction and the incidental losses due to it were the only resistances to flow, the vertical velocity curve would probably be curved in the lower part and straight in the upper part, the line being tangent to the curve at that point in the vertical where the effect of bed resistance is lost (fig. 7, *a*); or if the bed friction is of sufficient amount relatively to the depth the curve might be continuous to the surface (fig. 7, *b*). Varying degrees between *a* and *b* would be met with, depending on the relation of depth to velocity, condition of bed, etc. If there is resistance at the surface due to air friction only, there would be a similar effect on the form of the curve

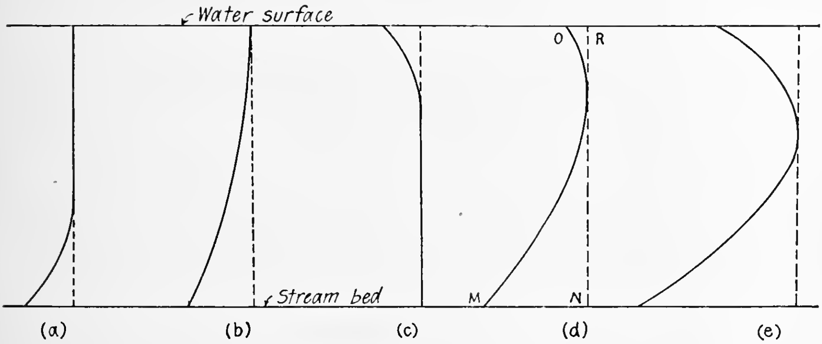


FIG. 7.—Form of vertical velocity curves.

from the surface downward. If there were no bed friction, the form of curve would be as in fig. 7, *c*, or some modification of this, as explained above.

Resistance to flow occasioned by the roughness of the sides of a stream is also an important factor in determining the form of the vertical velocity curve, especially if the channel is narrow and deep. F. P. Stearns[a] has advanced the theory that there is an upward flow toward the center at the surface. He says:

> Let us first suppose the case of a single obstacle projecting from the lining of a channel. The current approaching this obstacle loses some of its velocity just before reaching it, and thereby causes an excess of head in a small pyramid of water just above the projection.
>
> This excess of head in turn causes a transverse flow of the water in all directions; but the strongest transverse flow will be in the direction of the least resistance, which is, as a rule, vertically toward the surface.

[a] Trans. Am. Soc. Civil Eng., vol. 12, 1883, pp. 331 et seq.

The irregularities upon the surfaces of even the smoothest channel linings met within practice are very large in comparison with the size of the particles of water striking them, and they may be considered as obstacles present in all parts of the lining, each tending to produce an upward flow, as above indicated.

Although the tendency to upward flow is general, yet since it can not occur without a corresponding downward flow to replace the water which rises it follows that it will take place only in those portions of the width of the channel where the obstacles producing it are the more frequent and nearer the surface—i. e., generally at or near the sides.

It is therefore the theory that there is at the sides of channels an upward flow, due to the cause already described, which carries with it the slow-moving water always found in the immediate vicinity of channel linings, and that this water, reaching the surface, flows toward the middle of the channel, retarding by its slower movement the velocity of the surface layers, thereby causing the maximum velocity to be, in most cases, below the surface.

It must not be inferred from what has just been stated that the writer believes there is a continuous flow in the direction indicated, since it is well known that the motions of water are very irregular, particularly in channels with rough linings or variable sections, and that masses of water find their way from the bottom to the surface in the middle of the channel as well as elsewhere. The idea which he wishes to convey is that in most cases the resultants of these irregular movements are in the directions indicated.

The typical vertical velocity curve for open-water conditions (fig. 7, *d*) may be considered as due to a combination of these various resistances, but the amount and direction of the wind may change greatly the retardation due to air friction, and consequently the form of the curve. The relative effect of bed and surface friction will be in a measure shown by the difference in length of *mn* and *or*, or, in other words, the relation of surface and bottom velocities to the maximum velocity. If there is an ice cover the upper part of the vertical velocity curve will be still more curved (fig. 7, *e*), and, as shown later (pp. 78–79), may even be more pronounced in this way than the lower part.

The foregoing statements would apply to a straight stretch of river with the bed approximately parallel to the water surface. The usual uneven conditions of bed and banks have a modifying influence and tend to obscure more or less the relative effect of bed and surface friction. This relation of top and bottom velocity to the maximum will, however, serve to indicate something of the relative amount of resistance due to ice cover and to the stream bed, and will be briefly considered.

For open-water conditions the results from 78 vertical velocity curves under various conditions at gaging stations on New York streams are as follows:[a]

Relation of top, maximum, and bottom velocity for open-water conditions.

	Velocity in terms of mean velocity=1.00	Difference as regards maximum velocity.
Top	1.15	0.03
Maximum	1.18	
Bottom	.50	.68

[a] See Water-Sup. and Irr. Paper No. 76, U. S. Geol. Survey, 1903, p. 25, fig. 3.

The relation of air or water surface friction to that of bed friction is here $\frac{0.03}{0.68}$, or 0.044. (Compare with Francis's ratio of $\frac{1}{810}$ for still air, p. 16.)

For smooth ice cover, the comparative effect of bed and ice friction is shown for several cases in the following table. The average amount of resistance due to ice cover is 0.58 of that due to roughness of bed, but there is considerable variation from this amount.

Comparative effect of bed and ice friction on vertical velocity curves under smooth ice cover.

River and station.	Gage height.	Number of curves	Average depth.	Average velocity.	Difference as regards maximum velocity.		Ratio of 1 to 2.
					Top (1).	Bottom (2).	
	Feet.		*Feet.*	*Feet per second.*			
Kennebec, North Anson, Me...	3.48	18	2.6	1.17	0.22	0.62	0.35
	4.17	19	2.5	1.30	.30	.62	.48
	4.77	9	2.9	1.33	.40	.57	.70
Connecticut, Orford, N. H.....	4.15	18	4.0	1.04	.50	.66	.76
	5.59	7	4.6	1.08	.27	.72	.38
	6.00	7	4.9	1.11	.32	.72	.44
	6.70	21	5.8	1.23	.41	.65	.63
Fish, Wallagrass, Me..........	3.91	8	2.5	.90	.23	.51	.45
	5.04	8	3.6	1.25	.64	.74	.86
Winooski, Richmond, Vt......	....	26	1.6	2.12	.59	.77	.77
Wallkill, Newpaltz, N. Y......	....	5	8.0	2.18	.37	.65	.57
Mean..................	....	....	....	....	.39	.66	.58

For very rough ice cover, the frictional effect of ice cover is the greater of the two, averaging 1.28 times that for roughness of bed.

Comparative effect of bed and ice friction on vertical velocity curves under very rough ice cover.

River and station.	Number of curves.	Average depth.	Average velocity.	Difference as regards maximum velocity.		Ratio of 1 to 2.
				Top (1).	Bottom (2).	
		Feet.	*Feet per second.*			
Rondout Creek, Rosendale, N. Y........	4	5.3	0.74	1.02	0.55	1.86
Wallkill, Newpaltz, N. Y................	4	14.6	2.98	.81	.89	.91
Winooski, Richmond, Vt................	5	6.2	1.99	1.11	1.05	1.06
Mean........................	....	....	....	.98	.83	1.28

RELATION OF DEPTH AND VELOCITY TO FORM OF CURVE.

It is evident from the foregoing tables that for a given mean velocity the vertical velocity curve under ice cover becomes flatter as the depth increases, since the curvature due to top and bottom resistances is distributed through a greater distance. (See fig. 13, p. 83.) For a given depth, as the mean velocity increases, the curvature will become greater, as both top and bottom resistances increase with velocity.

For a given station the change in curvature as the stage increases will depend on the relative increase of depth and velocity. In the case of Wallkill River (fig. 10) the depth increases considerably faster than the velocity, and it will be noted that the curve becomes flatter as the stage increases.

COMPARISON OF VERTICAL VELOCITY CURVES, WITH AND WITHOUT ICE COVER.

Fig. 8 affords a comparison of mean vertical velocity curves for conditions of open water and ice cover, at substantially the same stations. The essential difference between these curves is the greater

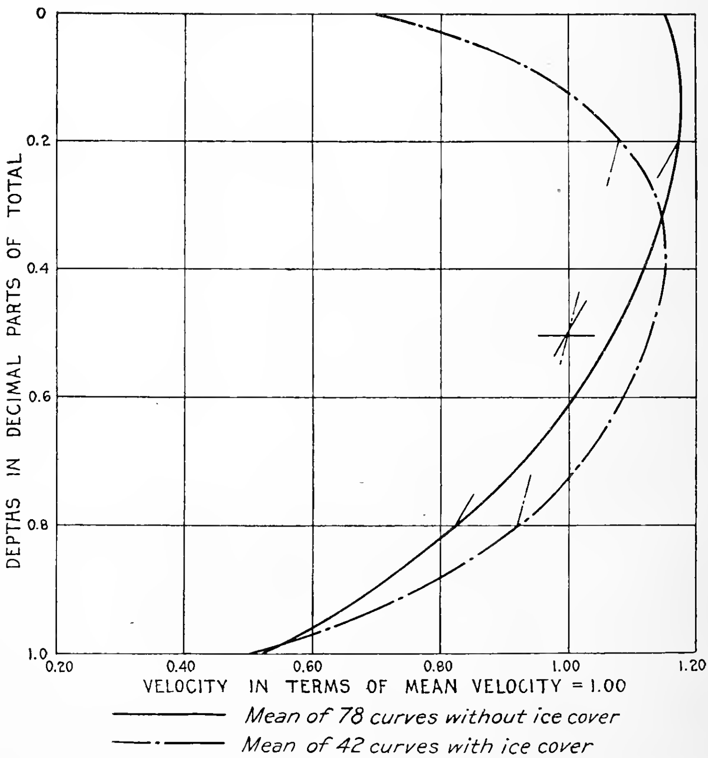


FIG. 8.—Comparison of vertical velocity curves for streams with and without ice cover.

drawing back of the curve for ice cover in its upper portion, on account of the greater retarding effect of the ice over that of air. As a consequence of this there are two threads of mean velocity, viz, at 0.13 and 0.71 of the depth, for ice cover, as compared to one mean thread at 0.61 depth for the open section. The position of maximum velocity is lowered from about 0.14 depth in the case of open section to 0.36 depth with ice cover, its relative value as regards mean velocity being

slightly less in the case of ice cover. The bottoms of the two curves are at substantially the same position, as would be expected.

With very rough ice cover the difference between the two curves becomes still more pronounced, and the drawing back of the curve in its upper part may predominate over the curvature existing in the lower part due to roughness of bed.

POSITION OF THREADS OF MEAN VELOCITY.

The data in the table on pages 73–74 and figs. 8 to 14 serve as a basis for the following discussions, except where special reference is made to other material.

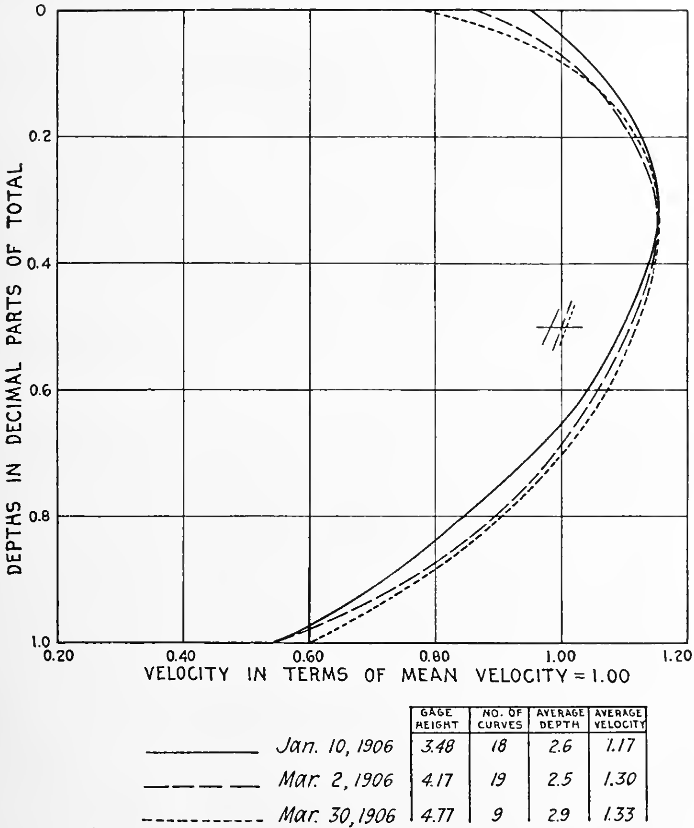


FIG. 9.—Vertical velocity curves under ice cover, showing change in form of curve with change of stage, Kennebec River at North Anson, Me.

The average of 352 vertical velocity curves made under widely varying conditions (pp. 73–74) indicates that in general under ice cover two threads of mean velocity occur in the vertical, their average position being at 0.10 and 0.71 of the depth below the bottom of the ice.

The depths of threads of mean velocity being plotted as ordinates and the total depths as abscissas, it is seen that there is a general tendency for both threads to move toward the bottom of the curve as depth increases. A similar plat for depths of threads of mean velocity and for mean velocities indicates that as mean velocity increases both threads of mean velocity become lowered. An increase in stage for a given station means usually an increase of both depth and mean velocity; consequently it will be found

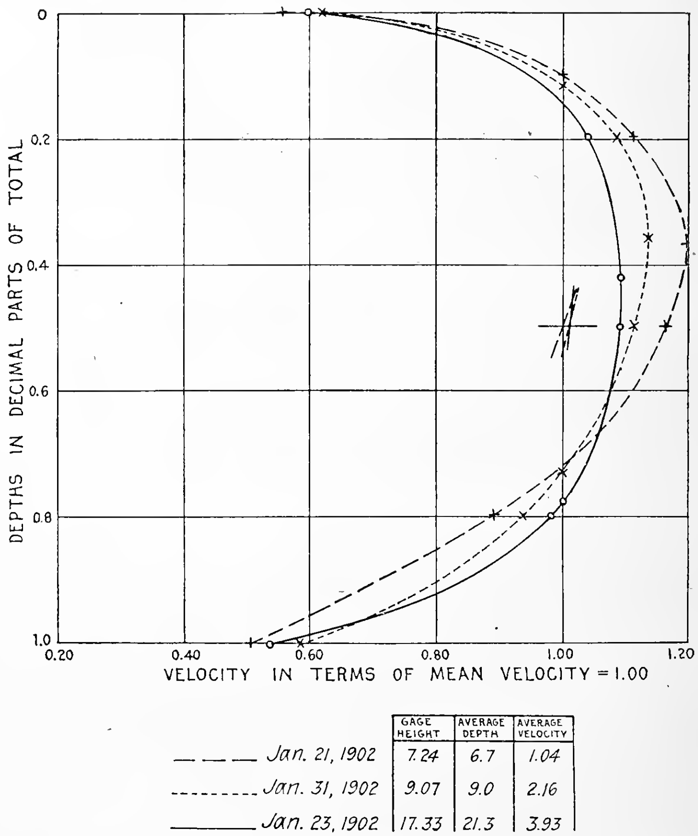


FIG. 10.—Vertical velocity curves under ice cover; average of curves at stations 80, 90, 100 for different stages, Wallkill River at Newpaltz, N. Y.

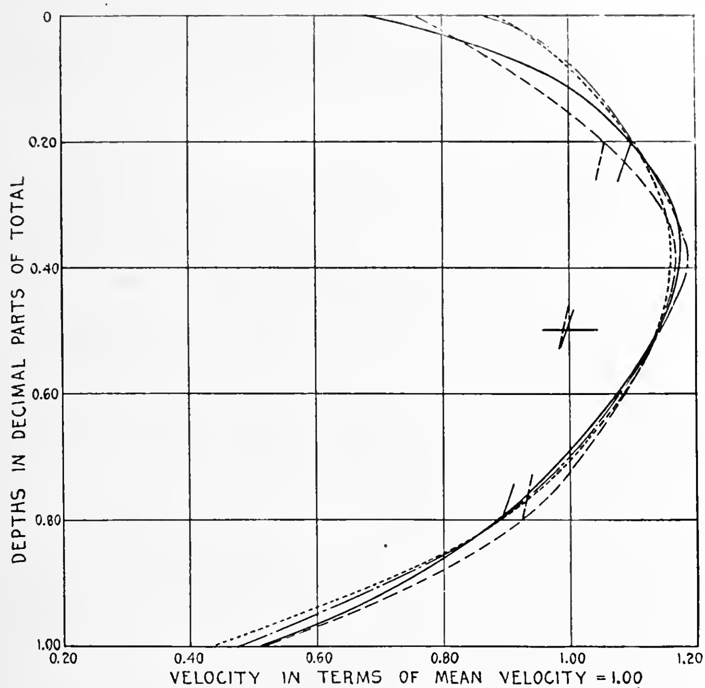
that both threads of mean velocity tend to move downward as the stage increases. (See figs. 9 to 11.)

The range in position of mean threads seems to be about the same for both upper and lower threads, being about 0.18 depth (with a few exceptions). Moreover, the change in position of the two threads is about the same in amount, the average difference being 0.60 of the depth. With very rough ice cover the tendency is toward greater depression of both mean threads, but it will be

noted that they still preserve about the same distance apart, viz, 0.60 depth. (See table on pp. 73–74, and fig. 14, p. 84).

POSITION OF MAXIMUM VELOCITY AND RELATION TO MEAN VELOCITY.

The average position of maximum velocity is at 0.37 depth below the ice, varying from 0.19 to 0.52 depth. In general, it becomes



	GAGE HEIGHT	NO OF CURVES	AVERAGE DEPTH	AVERAGE VELOCITY
Feb. 1905	4.15	18	4.0	1.04
Feb. 1906	6.70	21	5.8	1.23
Mar. 1906	6.00	7	4.9	1.11
Mar. 1906	5.59	7	4.6	1.08

FIG. 11.—Vertical velocity curves under ice cover, showing change in form of curve with change of stage, Connecticut River at Orford, N. H.

lower as the depth and velocity increase and hence as the stage increases. Rough ice cover tends also to lower the depth of the maximum thread, and when the ice becomes broken and tilted or when needle ice accumulates near its under surface the thread may be considerably below mid depth, indicating a greater effect due to ice friction than to that of the stream bed; in other words, the curve is a complete reversal of the ordinary open-water vertical velocity curve.

The average coefficient to apply for obtaining maximum from mean velocity is 0.839, the variation being from 0.76 to 0.90. This coefficient becomes less as the velocity increases, but greater as the depth increases, consequently its variation from the mean is not large for smooth ice. For rough ice it is considerably diminished and may reach a value of 0.75.

RELATION OF VELOCITY AT MID DEPTH TO MEAN VELOCITY.

The average coefficient for obtaining mean velocity from that at mid depth is 0.878, the range being from 0.82 to 0.92. The range

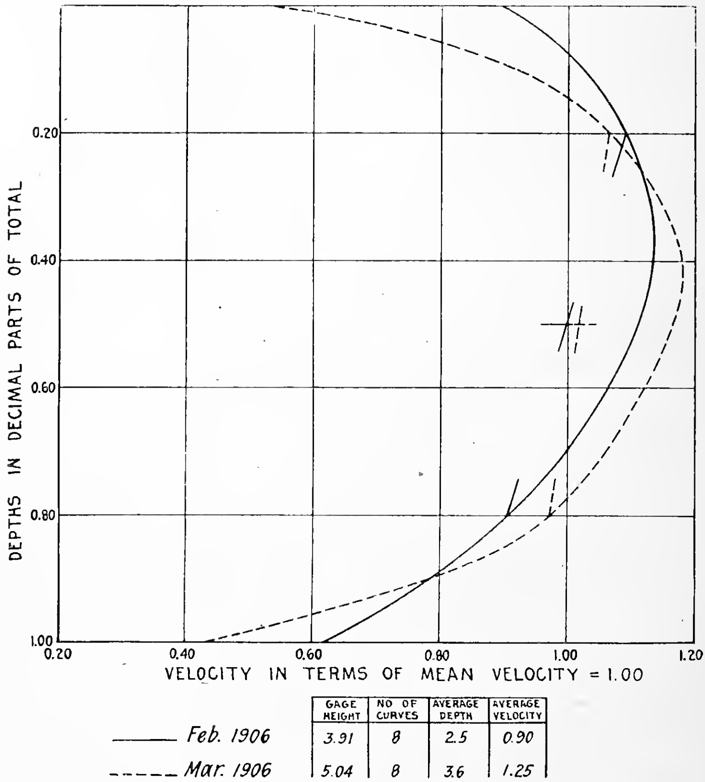


FIG. 12.—Vertical velocity curves under ice cover, Fish River at Wallagrass, Me.

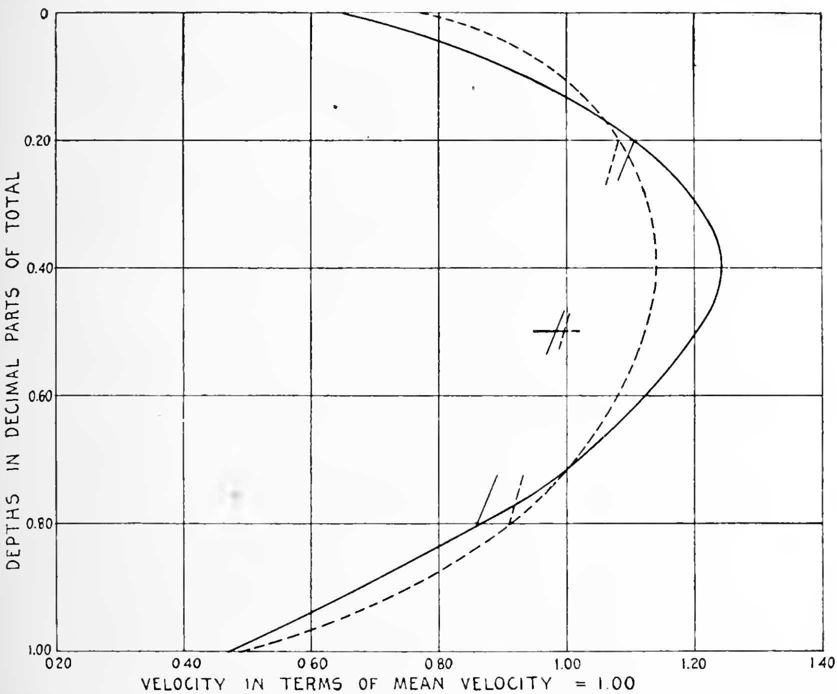
in values for this coefficient, like that for maximum velocity, is small, as the tendency is for it to increase directly with the depth and inversely with the velocity; consequently for a given station little variation occurs as the stage changes. Nearly this same average relation was found on the upper Mississippi by A. O. Powell, assistant engineer, under the direction of Col. Charles J. Allen, Corps of Engineers, U. S. Army, in 1882 and 1890,[a] the variation being

[a] Ann. Rept. Chief of Engineers, U. S. A., 1890, pt. 3, p. 2104.

between 0.87+ and 0.88+. No data are given, however, as to conditions of depth, velocity, or bed of stream. The coefficient for obtaining mean velocity from that at mid depth becomes less for very rough ice, just as in the case for maximum velocity, the average value for the 13 curves being 0.82, with a range of from 0.76 to 0.85.

RELATION OF MEAN OF VELOCITIES AT 0.2 AND 0.8 DEPTH TO MEAN VELOCITY.

The average coefficient for obtaining mean velocity from the mean of the velocities at 0.2 and 0.8 depth is 1.002, the range being from



	BED	NO OF CURVES	AVERAGE DEPTH	AVERAGE VELOCITY
——— Winooski River at Richmond, Vt.	Gravel	26	1.6	2.12
- - - - Wallkill River at Newpaltz NY	Clay & Cobbles	5	8.0	2.18

FIG. 13.—Effect of depth on form of vertical velocity curves under ice cover.

0.98 to 1.04, there being, however, but one set of curves with a greater value than 1.02. This relation is shown graphically by connecting the 0.2 and 0.8 depth points of the mean vertical velocity curves and noting where this line crosses the horizontal at 0.5 depth. (See figs. 8 to 13.)

In general, this coefficient seems to decrease slightly as gage heights increase. (See figs. 8 to 11, and table on pp. 73–74.) For very rough ice cover the mean value is 1.002, the range being from 1.00

to 1.04, indicating that rough ice tends to increase this coefficient slightly.

The typical vertical velocity curve for open-water conditions corresponds approximately in form with an ordinary parabola drawn through top, bottom, and mid-depth points of the curve and with axis horizontal. The mean ordinate to this parabola is a mean of the ordinates at 0.22 and 0.79 of the depth, and it is evident that the mean of the ordinates at 0.2 and 0.8 depth would always be less than the true mean ordinate, so that if the vertical velocity

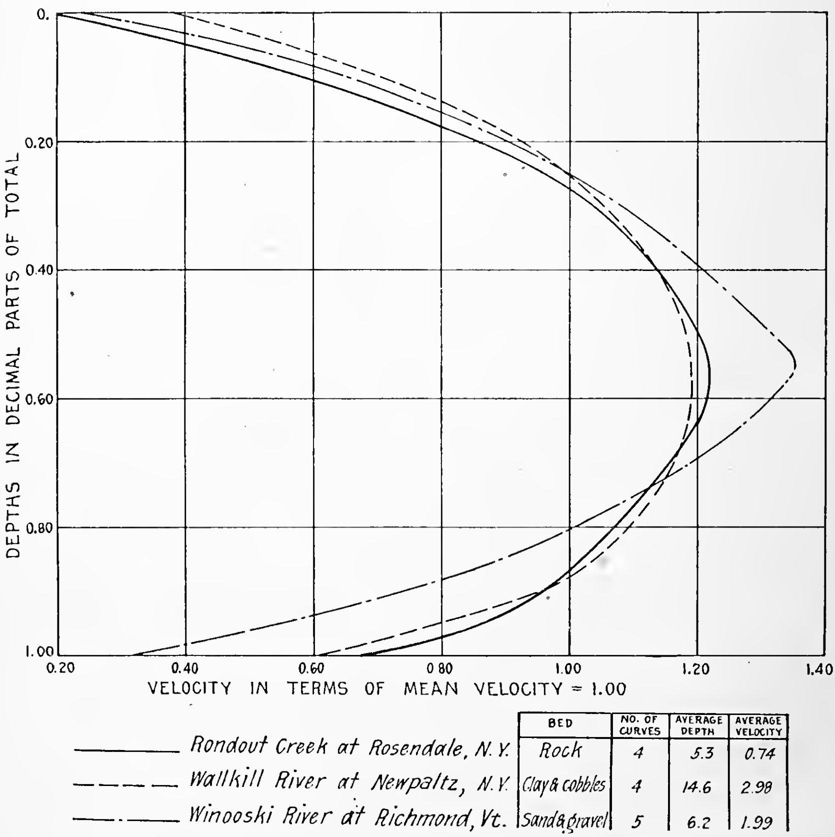


FIG. 14.—Effect of very rough, broken, and tilted ice on form of vertical velocity curves under ice cover.

curve were truly parabolic the coefficient for this method would always be slightly greater than 1.00. Usually the parabola passes wholly to one side of the actual curve above mid depth and on the opposite side below mid depth, the resulting effect being that the mean of the velocities at 0.2 and 0.8 depth ordinarily gives closely the mean velocity for the vertical.

For ice cover the vertical velocity curve diverges markedly from a parabola drawn as described above. The results of the table on pages 73–74 seem to indicate, however, that this relation holds almost

as well for curves under ice cover as with open section, and the 0.2 and 0.8 method, as it is called, seems to have much promise as a two-point method, being both reasonably accurate and convenient for use.

The range of variation in the reduction of coefficients is as follows:

Range of coefficient to reduce to mean velocity.

Maximum	0.14
Mid depth	.10
0.2 and 0.8 depth	.06

The accuracy of the method being assumed to be proportional to the square root of the number of observations, and either of the single-point methods being adopted as a basis, the computed probable range of error for the two-point method would be

$$\frac{\text{Range for single point}}{\sqrt{2}},$$

or, as compared with maximum point, the range would be 0.099; with mid-depth point, the range would be 0.071. The actual range of variation for the two-point method is considerably smaller, indicating that it has a greater accuracy as compared with single-point methods than can be attributed to the use of two observations instead of one.

PERCENTAGE VARIATION IN OBSERVATIONS AT DIFFERENT DEPTHS.

In general the top and bottom of the vertical velocity curve is most poorly determined, because greater variations occur in velocity in these portions of the curve. The 0.5 depth method has the advantage of utilizing a depth of observation at which variations in velocity are least apt to occur.

As bearing on the variations between successive observations at 0.2 and 0.8 depth, the following table gives results from two sets of curves where independent observations were made at these depths just after the curves were completed:

Variation in observations at 0.2 and 0.8 depth, Connecticut River at Orford, N. H., meter suspended from cable.

MARCH 14, 1906, GAGE HEIGHT, 6.00.

	Observed velocity. Ratio: Velocity from curve.		Ratio of velocity determined by the 0.2 and 0.8 method to the mean velocity.		Depth under ice.	Mean velocity.
	0.2 depth.	0.8 depth.	Actual observation.[a]	From curve.[b]		
					Feet.	*Feet per second.*
Average of 7 curves	0.993	0.995	1.013	1.004	5.0	1.10
Highest	1.07	1.05	1.04	1.02	6.3	1.39
Lowest	.94	.95	.98	.99	3.5	.56

[a] Mean from 0.2 and 0.8 velocity as observed.
[b] Mean from 0.2 and 0.8 velocity taken from vertical velocity curve.

Variation in observations at 0.2 and 0.8 depth, Connecticut River at Orford, N. H., meter suspended from cable—Continued.

MARCH 15, 1906, GAGE HEIGHT 5.59.

	Observed velocity Ratio: Velocity from curve.		Ratio of velocity determined by the 0.2 ahd 0.8 method to the mean velocity.		Depth under ice.	Mean velocity.
	0.2 depth.	0.8 depth.	Actual observation.	From curve.		
					Feet.	*Feet per second.*
Average of 7 curves	1.006	0.974	1.011	1.003	4.6	1.08
Highest	1.04	1.13	1.05	1.01	5.7	1.36
Lowest	.95	.90	.97	.99	3.2	.51

As would be expected, the actual observations at 0.2 and 0.8 depth, when used to obtain mean velocity, give a larger percentage variation in coefficient than do the curve values at these depths, but the average variation is small and far within the degree of accuracy required.

A further index of the amount of variation in observations at 0.2 and 0.8 depth is afforded by two successive gagings made February 15, 1906, on Fish River at Wallagrass, Me., under ice cover, when the gage heights height remained the same.

Comparison of velocities for two separate gagings on Fish River at Wallagrass, Me., gage height 3.91, meter fastened to rod.

FEBRUARY 15, 1906, GAGE HEIGHT 3.91.

	Ratio of velocities obtained in first and second gagings.			Depth.	Mean velocity.
	0.2 depth.	0.8 depth.	Mean		
				Feet.	*Feet per second.*
Average of 4 stations, observations at 0.2 and 0.8 depth	1.002	0.972	0.990	2.6	0.88
Highest	1.06	1.08	1.05	4.1	1.10
Lowest	.93	.91	.94	.9	.62
Average of 4 stations, vertical velocity curves			0.978	2.5	.90
Highest			1.01	3.6	1.18
Lowest			.95	1.3	.86

Other details of these gagings are given on page 53. It will be noted that the depths are small and that in order to get 0.2 and 0.8 depth the meter had to be held within a range of 0.2 to 0.8 feet from the bottom of the ice and the bed of the river. The average variation in the results of these two sets of velocities at 0.2 and 0.8 depth is small and, in fact, is less than in the case of the vertical curves.

SLOPE DETERMINATIONS AND VALUES OF *n* IN KUTTER'S FORMULA, UNDER ICE CONDITIONS.

In 1906 two sets of slope determinations and measurements of the other hydraulic properties were made on Connecticut River at Orford, N. H.

February 17, 1906.—River in general frozen. A strip of open water, beginning at bridge, extended about 1,000 feet downstream. This was about 100 feet wide and approximately in the middle of the channel. The ice was rough in places and numerous ice cakes were frozen in, owing to high water and a partial going out of the ice during January. There were about 11 inches of snow on the ice.

Bench marks, consisting in most cases of spikes in trees, were established along each bank by a double-rodded line of levels. Soundings for determination of cross section were made at 100 feet, 250 feet, and 516 feet upstream from the gage. The level was set on the ice in the middle of the river, and water-surface elevations were determined on both banks at each section at holes cut in the ice. The following table gives results of the best set of observations:

Slope determinations and value of "n" on Connecticut River at Orford, N. H., February 17, 1906.

[Gage height to water surface, 6.65 feet; gage height to bottom of ice, 5.15 feet; gage height to top of ice 6.67 feet; discharge, 2,070 second-feet.]

Distance of section from gage.	Width below ice.	Area below ice.	Velocity.	Wetted Perimeter.	Hydraulic Radius.	Distance between sections.	Difference in elevation of water surface.	Slope.	Average Hydraulic radius.	Average velocity.	*n*.
Feet.	*Feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*		*Feet.*	*Ft. per sec.*	
516	302	2,110	0.98	605	3.49	266	0.026	0.000098	3.12	1.04	0.030
250	340	1,890	1.10	685	2.76	150	.043	.000287	2.70	1.15	.042
100	329	1,730	1.20	659	2.63						

March 15, 1906.—The conditions were about the same as during February, but the strips of open water were considerably shorter and narrower. There was no snow on the ice. Iron rods 4 or 5 feet long were driven into the bank to within about 6 inches of the water surface in holes cut in the ice. These were located on each bank at sections 100 feet, 296 feet, and 516 feet upstream from the gage and the elevation of the tops was determined by several series of levels. Measurements were then made from these points to the water surface with a 2-foot rule. Independent observations were made at each point by two men, each man's set being averaged separately and the mean of the two sets being finally used. The results were as follows:

Slope determinations and value of "n" on Connecticut River at Orford, N. H., March 15, 1906.

[Gage height to water surface, 5.62 feet; gage height to bottom of ice, 4.18 feet; gage height to top of ice 6.67 feet; discharge, 2,070 second-feet.]

Distance of section from gage.	Width below ice.	Area below ice.	Velocity.	Wetted perimeter.	Hydraulic radius.	Distance between sections.	Average hydraulic radius.	Average velocity.	Series.	Difference in elevation of water surface.	Slope.	n.
Feet.	*Feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Ft per sec.*		*Feet.*		
516	295	1,800	0.83	592	3.04	220	2.67	0.90	1	0.020	0.000091	0.030
									2	.020	.000091	.030
									3	.024	.000109	.033
296	330	1,530	.98	662	2.31	196	2.28	1.01	1	.030	.000153	.030
									2	.031	.000158	.031
100	319	1,440	1.04	640	2.25				3	.030	.000153	.030

Conclusions.—The mean value of *n* for the February obsevations is 0.036, and for the March observations is 0.031. The March series are much the more reliable of the two.

DATA FROM OTHER SOURCES.

Up to the present time very little information has been published on the flow of streams under ice cover, other than that gathered by the United States Geological Survey.[a]

Raucourt made experiments on the Neva[b] at a point where it is 900 feet wide and of regular section, the maximum depth being 63 feet. When the river was frozen over the maximum velocity (2 feet 7 inches per second) was found a little below the middle of the deepest vertical. It was somewhat less than double the velocity at the surface and bottom, which were nearly equal to each other.

The United States Engineer Corps[c] recently made some current-meter measurements of flow under ice cover on St. Marys River.

No details of the observations are given, but the general results were as follows: (1) The location of the threads of mean velocity was found to be at 0.067 and 0.753 depth. (2) The maximum velocity was found to be at approximately 0.4 depth. (3) The friction caused by the ice was found to be 0.309 of that caused by the bottom.

Further measurements under ice cover on St. Marys River were made during 1905, but have not yet been reported for publication.

Considerable data on conditions in the frozen period, duration of the frozen season, etc., may be found in the proceedings of the International Meteorological Congress, Chicago, 1893.[d]

[a] Water-Sup. and Irr. Papers Nos. 76 (1903) and 95 (1904).

[b] Humphreys and Abbot, Physics and Hydraulics of Mississippi River, p. 190.

[c] Rept. Chief of Engineers for 1897, p. 4092.

[d] The four great rivers of Siberia: Bull. U. S. Weather Bureau No. 11, 1893.

CONCLUSIONS.

PRACTICABILITY OF WINTER ESTIMATES OF FLOW.

The classification of current-meter gaging stations on page 9 indicates that about one-sixth of them remain open during the winter and permit about the same degree of accuracy for winter estimates as for those of the summer; they can, therefore, be classed with stations south of the area subject to ice cover. About one-third of these stations usually have a smooth, permanent ice cover, and it is probably fair to assume that this is about the proportion at which winter estimates that will be fairly reliable can be made without too great cost. Undoubtedly there is a further number of stations where good estimates can be made if sufficient attention is given by the hydrographer, and particularly if an intelligent gage reader, with ability to note and sketch conditions affecting flow, is available.

Stations at dams, in general, give less trouble during the winter than current-meter stations, and this should be kept in mind where there is any question as to which form of station is preferable.

RECOMMENDATIONS AS TO METHODS.

The study of the flow of streams under ice cover is but just started, and in order to systematize the accumulation of data and to provide the material in convenient form for future use it is desirable that certain general methods be followed.

The methods of obtaining gage heights used should be as described on pages 21–23, and the observer should be especially encouraged to note any unusual conditions affecting flow, furnishing sketches where desirable. It should be kept in mind that what is desired is the *average* thickness of ice, distance from bottom of ice to water surface, etc., for the portion of the river near the gage, and that the hole cut in the ice should be so located as to give average results; preferably, several holes should be cut from time to time. The cost of current-meter measurements under ice cover can be kept within reasonable limits by employing laborers when necessary to cut holes in the ice, so as to utilize to better advantage the time of the hydrographer, and by using the two-point method of observations at 0.2 and 0.8 depth, with a few vertical velocity curves, if possible, for purposes of study. In case time is short a single observation at 0.5 depth will give fairly good results, the coefficient 0.88 being applied, or if a few vertical curves have been taken a closer value of the coefficient can be determined from them.

By following the above suggestions the total time required for a gaging will not be usually more than half a day, and the cost will be but little greater than that for a gaging under open-water conditions.

For depths less than 5 feet it is desirable to use the current meter fastened to a rod for convenience in handling and in order that 0.8 depth may be reached; in fact, this method is generally preferable to the use of a cable where depths and velocities are not too great.

Vertical velocity curves should be taken at typical points in the cross section when time permits just as for open water. These should always be taken just before or after the two or one point observations at the point in question to give further information as to the field accuracy of these methods, the observations by the point method not being incorporated in the vertical velocity curve.

Rating curves should be constructed in each of the two ways described on pages 43–46, and the method which seems to give the best results should be used. Special efforts should be made to obtain gagings for thin ice cover for the purpose of better defining the rating curve or coefficient to use under such conditions.

It is believed that the methods previously indicated for discharge measurements (pp. 22–24) will give results well within the degree of accuracy consistent with winter estimates of flow, and that less time need be spent hereafter on individual gagings. This will make it possible to give more attention to the study and completion of station rating curves—the direction in which the most effort should be expended in the immediate future.

INDEX.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 187.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the nineteenth in Series M, the complete list of which follows (WS=Water-Supply Paper):

SERIES M—GENERAL HYDROGRAPHIC INVESTIGATIONS.

WS 56. Methods of stream measurement. 1901. 51 pp., 12 pls.
WS 64. Accuracy of stream measurements, by E. C. Murphy. 1902. 99 pp., 4 pls.
WS 76. Observations on the flow of rivers in the vicinity of New York City, by H. A. Pressey. 1902. 108 pp., 13 pls.
WS 80. The relation of rainfall to run-off, by G. W. Rafter. 1903. 104 pp.
WS 81. California hydrography, by J. B. Lippincott. 1903. 488 pp., 1 pl.
WS 88. The Passaic flood of 1902, by G. B. Hollister and M. O. Leighton. 1903. 56 pp., 15 pls.
WS 91. Natural features and economic development of the Sandusky, Maumee, Muskingum, and Miami drainage areas in Ohio, by B. H. Flynn and M. S. Flynn. 1904. 130 pp.
WS 92. The Passaic flood of 1903, by M. O. Leighton. 1904. 48 pp., 7 pls.
WS 94. Hydrographic manual of the United States Geological Survey, prepared by E. C. Murphy, J. C. Hoyt, and G. B. Hollister. 1904. 76 pp., 3 pls.
WS 95. Accuracy of stream measurements (second edition), by E. C. Murphy. 1904. 169 pp., 6 pls.
WS 96. Destructive floods in the United States in 1903, by E. C. Murphy. 1904. 81 pp., 13 pls.
WS 106. Water resources of the Philadelphia district, by Florence Bascom. 1904. 75 pp., 4 pls.
WS 109. Hydrography of the Susquehanna River drainage basin, by J. C. Hoyt and R. H. Anderson. 1904. 215 pp., 28 pls.

WS 116. Water resources near Santa Barbara, California, by J. B. Lippincott. 1904. 99 pp., 8 pls.

WS 147. Destructive floods in the United States in 1904, by E. C. Murphy and others. 1905. 206 pp., 18 pls.

WS 150. Weir experiments, coefficients, and formulas, by R. E. Horton. 1906. 189 pp., 38 pls.

WS 162. Destructive floods in the United States in 1905, by E. C. Murphy and others. 1906. 105 pp., 4 pls.

WS 180. Turbine water-wheel tests and power tables, by Robert E. Horton. 1906. 134 pp., 2 pls. (Out of stock.)

WS 187. Determination of stream flow during the frozen season, by H. K. Barrows and Robert E. Horton. 1907. 93 pp., 1 pl.

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DECEMBER, 1906.

O